Biodiversity of the Arctic Ocean

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The history of Arctic faunal studies in Russia began more than 200 years ago. As early as the end of the eighteenth century the Zoological Museum acquired its first collections from the Barents, Kara, and White seas. Since then Russian scientists have obtained samples from more than 14,000 stations in Arctic seas, most of which were from the Barents and White seas. The number of samples collected from these stations is several times higher than the number of stations. A large part of the material obtained has been deposited in the scientific collections of the Zoological Institute. There are more than 90,000 samples of different animal taxa collected from the Arctic seas in the collections.

There are several institutions that participated in the study of the Arctic marine flora and fauna in Russia, including four institutions at the Russian Academy of Sciences: Zoological Institute in St. Petersburg, Institute of Oceanography in Moscow, Murmansk Marine Biological Institute in Murmansk, and Botanical Institute in St. Petersburg. Colleagues from the Institute of Oceanography studied materials collected in the Barents and Kara seas before the Second World War and materials of several Russian drift ice stations in the Canada Basin, *North Pole 22* (1976-1978, 1978-1979, 1980), and in the Makarov Basin, *North Pole 23* (1977). Moreover, in 1993 the Institute of Oceanography carried out an expedition into the Kara Sea; 68 samples were collected. During 1988-2000 the Murmansk Marine Biological Institute carried out 26 expeditions into the Barents, White, and Kara seas. About 2,000 samples at 630 stations were collected during these expeditions. Between 1967-1989, the Zoological Institute carried out 12 expeditions into different Arctic seas from the Barents to the Chukchi Sea where more than 1,000 samples were collected. In shallow waters to a depth of 40 m, quantitative investigations were performed using scuba. This method allows for more precise results to be obtained on the predominantly hard substrate in the upper parts of the shelf and among algae than the quantitative analysis of abundance and distribution using grabs or trawls from a research vessel.

In the beginning of the 1990s, a freedom enveloped Russia and a possibility of closer cooperation of Russian scientists with foreign colleagues appeared. The fall of the Iron Curtain allowed organizing several expeditions, which were financed mainly by Western countries (Germany, Norway, United States, and others). Scientists from the Zoological Institute took part in 14 expeditions aboard Russian, German, and U.S. vessels. About 1,000 samples at 470 stations were collected during these expeditions.

The study of the rich material collected during the last nine years has allowed us to considerably increase our knowledge about species diversity of the insufficiently studied Siberian seas, such as the East Siberian, Chukchi, and Laptev seas. As a result of seven expeditions on board the German icebreaker *Polarstern* (1993, 1995, 1998) and the Russian research vessels *Ivan Kireev* (1993), *Prof. Multanovsky* (1994), *Capitan Dranitzin* (1995), and *Jakov Smirnitsky* (1995) almost 400 more species were discovered in the Laptev Sea alone. Some of the above-mentioned and several other expeditions also worked in other Arctic seas besides the Laptev Sea and in the adjacent deep waters of the Arctic Basin, which resulted in the addition of many more species to their species lists.

The book *List of Species of Free-Living Invertebrates of Eurasian Arctic Seas and Adjacent Deep Waters* is a result of our investigations during the last ten years. It includes about 4,800 species of invertebrates. The area covered extends from Svalbard, Bjørnøya, and Nordkapp (25°47'E) in the western Arctic to Point Barrow (157°W) in the east and includes the White, Barents, Kara, Laptev, East Siberian, and Chukchi seas and the deep-water part of the central Arctic Basin adjacent to these seas. The lists of species were prepared mainly by the most skilled taxonomists in Russia (Zoological Institute of the Russian Academy of Sciences [RAS], P.P. Shirshov Institute of Oceanography of the RAS, Institute of Marine Biology, Far Eastern Branch of RAS, St. Petersburg State University, Moscow State University) and the Ukraine (Institute of Biology of Southern Seas of the Ukrainian Academy of Sciences, Kharkov State University). Fifty-nine taxonomists took part in compiling the lists. Lists of only six small invertebrate taxa were compiled by non-specialists including Acari, Tanaidacea, Cladocera, Phoronida, Enteropneusta, and Appendicularia. Most species lists were prepared using collections, published and unpublished catalogues, and literature data. The lists cannot be considered a complete listing of all species inhabiting Eurasian seas of the Arctic because non-described species in collections of the Zoological Institute were usually not included. In the future, these lists should be updated regularly. The present version was completed in May-September 2001 for different invertebrate taxa. The present up-to-date checklist is the first step in producing "Illustrated Keys for the Identification of Free Living Invertebrates of Eurasian Seas of the Arctic," which the Zoological Institute intends to publish in the near future.

The most species rich Eurasian sea of the Arctic is the Barents Sea, inhabited by 3,245 invertebrate species. The White Sea fauna is an impoverished Barents Sea fauna comprising 1,817 species. The number of species steadily declines eastward from the North Atlantic: 1,671 species are known for the Kara Sea, 1,472 for the Laptev Sea, 1,011 species for the East Siberian Sea, and 1,168 species for the Chukchi Sea. These figures suggest a notable influence of the Atlantic Ocean on the faunal composition. Pacific species play a minor role; their importance shows in the Chukchi Sea (mainly), the Beaufort Sea, the east Siberian Sea, and in the eastern part of the Laptev Sea. There are 837 known species in the deep-water part of the central Arctic Basin adjacent to Eurasian seas.

Species composition of the Barents and White seas is best compared to other Arctic seas. Species composition of some groups (Ciliophora, Turbellaria, Harpacticoida, Nemertini, and Nemathelminthes) in the White Sea is better studied than in other Arctic seas owing to several biological stations permanently maintained in the White Sea. Fauna of the Kara, Laptev, and Chukchi seas is less known, and the species composition of the east Siberian Sea is the least known.

The fauna of Arctic marine invertebrates comprises three large groups: macrobenthos, comprising 60% of the species, meiobenthos—34%, and plankton—approximately 6%. Our knowledge of planktonic organisms, which have a lower species diversity and a wider distribution range compared to benthic animals, is more complete. Different benthic groups have been studied to varying degrees. The study of species diversity started with large organisms. Therefore, macrobenthos is better studied than meiobenthos. Meiobenthic groups such as nematodes, turbellarians, harpacticoids, and ostracods are particularly poorly studied. Several groups of invertebrates are variable in the study areas: Sarcomastigophora, Ciliophora, Annelida, Crustacea, and Mollusca.

Analysis of the distribution of different benthic biocenoses in the Eurasian seas has allowed us to establish some regularities. It turns out that belts with dominant groups of animals are typical for these seas. The estuarine Arctic complex with species such as *Portlandia aestuariorum* and *Cyrtodaria curriana* inhabits areas close to large rivers. There is a very broad belt of the biocenosis dominated by different species of bivalves in the more open waters. More than ten species of bivalves, such as *Astarte borealis*, *Macoma calcarea*, *Portlandia arctica*, *Leionucula tenuis*, *Nuculana pernula*, *Nuculana radiata,* and others inhabit the belt. At a depth of 60-540 m there is also a broad belt of the biocenosis dominated by brittle stars (*Ophiocten sericeum*, *Ophiopleura borealis*, *Ophiocantha bidentata*) and different species of polychaetes.

At depth greater than 540 m ophiuroids disappear as the dominant group in grab samples. At most stations polychaetes keep the dominant position or share it with sponges, coelenterates, bivalves, sipunculids, holothurians, or rarely with other groups of invertebrates.

Between the depths of 1,580 m to 3,310 m the members of the deepwater complex are met with groups of typical species. These are holothurians (*Kolga hyalina*, *Elpidia heckeri*), sea urchins (*Pourtalesia jeffreysi*) and bivalves (*Cyclopecten frigidus*). However, so far we have not been able to distinguish a special community where the abovementioned species are dominant because the species composition of these areas differs little from adjacent areas and, moreover, the main dominants in these areas often turn out to be polychaetes.

In the northern part of the Laptev Sea in the region where Gakkel Ridge meets the continental slope, the subfossil shells of mollusks of the genus *Archivesica* were found in two samples on station 50 (*Polarstern*, 1993, 77º41.43 to 77º41.10'N; 125º55.68-125º54.16'E, depth 1,993-1,992 m) and station 3 (*Polarstern*, 1995, 77º46.1'N; 126º07.3'E, depth 2,054 m). These mollusks are the characteristic member of homotrophic communities. Morphological analysis of these shells showed that they are very closely related to the Californian species *Archivesica* but are rather a new species. The composition of fauna and some other features of station 50 deserve special attention. The total number of dead and live species of benthic animals in the trawl was 37. Three shallow water bivalves (*Astarte montague*, *Serripes groenlandicus*, *Hiatella arctica*) occurred only as empty shells, and presumably were transported in ice rafts from the Laptev Sea shelf. The rest of the 34 species were either deep water or ubiquitous. Among them polychaetes (*Nicomache* aff. *trispinata* and *Capitella capitata*), isopods (*Saduria sabini megaluroides*), gastropods (*Mohnia danielsseni*) and sea cucumbers (*Kolga hyalina*) were the dominants. The species number of the trawl station 50 (34 species) was poorer than that from the neighboring stations 32 (36 species) and 54 (38 species), although these stations were deeper (3,012-3,028 and 3,039-3,042 m, respectively).

During the last ten years we cooperated mainly with German colleagues from the Alfred Wegener Institute for Polar and Marine Research and from the Institute of Polar Ecology. The product of our collaborations with the Alfred Wegener Institute is a set of articles on the fauna of the Laptev Sea and the book *Biodiversity of the Weddell Sea: Macrozoobenthic Species* (demersal fish included) sampled during the expedition ANT XIII/3 (EASIZI) with RV *Polarstern*. Our institute also maintains an active collaboration with the University of Alaska Fairbanks and Norwegian Akvaplan-niva in the study of biodiversity in the Barents and Chukchi seas.

Biodiversity of Free-Living Invertebrates in the Far Eastern Seas and the Proposition of NaGISA Transects around the Bering Sea

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The Vitus Bering Expedition started Russian investigations of the Far Eastern seas in the first half of the eighteenth century. Since then about 150 expeditions have been organized in those regions. A rapid increase in the investigation of marine fauna occurred in the 1960s when Russian scientists began using scuba equipment. Aqualung permitted studies of previously inaccessible shallow water areas with predominantly rocky and gravel substrate. Valuable material on invertebrate fauna has been obtained since the early 1980s as a result of using the submarine vehicles *TINRO-2, Sever-2, Pisces*, and *Mir* in deeper waters.

During the entire study period of Far Eastern seas approximately 15,000 stations were sampled and a large number of samples were taken. Unfortunately, taxonomists examined only part of the material; some of it was lost. Most of the preserved material has been deposited in scientific collections at the Zoological Institute in St. Petersburg. The remaining material was deposited in the Institute of Oceanography at the Russian Academy of Sciences, the Zoological Museum at Moscow State University in Moscow, the Institute of Marine Biology at the Russian Academy of Sciences in Vladivostok, and in the Kamchatka Institute of Ecology and Nature Management at the Russian Academy of Sciences in Petropavlovsk-Kamchatski.

Here, I am reporting results on the analysis of biodiversity of invertebrate fauna inhabiting the Russian part of the Far Eastern seas. The American fauna of the eastern part of the Bering Sea and fauna of the southern part of the Sea of Japan are not taken into account. The entire study region is divided into five areas: Bering Sea,

Sea of Okhotsk, Sea of Japan, Pacific coast of Kamchatka including the Commander Islands and the north and middle Kurile Islands and, separately, the south Kurile Islands.

Information obtained from leading scientists in Russia and published data have permitted me to characterize the diversity of marine invertebrates in each of the above-mentioned areas and also to show the degree of knowledge available about them. It appears that the fauna of free-living marine invertebrates in the Far Eastern seas of Russia includes 5,940 species. This does not include species of several groups: Cyclopoida, Rotatoria, and Appendicularia. Apart from free-living species, about 900 parasitic invertebrate species are known from the Far Eastern seas. Species distribution of different taxonomic groups suggests that the most numerous invertebrates are the arthropods, consisting primarily of about 1,700 species of crustaceans. Next to them in diversity are the mollusks (more than 600 species), protozoans (approximately 500 species), tentaculates (more than 400 species), and echinoderms (around 400 species). Analysis of species distribution in ecological groups shows the greatest diversity for macrobenthos (around 4,500 species), and less for meiobenthos (882 species) and plankton (592 species).

Comparison of the invertebrate fauna within areas of the Far Eastern seas reveals a regular decline in the number of species from south to north (from 2,900 species in the Sea of Japan to 2,000 species in the Bering Sea). Therefore, the Sea of Japan appears to be the most species rich within the five regions that were separated. Following the Sea of Japan is the Sea of Okhotsk, the region from the middle Kurile Islands to the Commander Islands, the south Kurile Islands, and lastly the Bering Sea.

Over the past 40 years the pace of studying biodiversity has increased considerably. Comparison of recent data with the data published by P. Ushakov (1953) and L. Zenkewitsh (1963) shows that the number of species of known invertebrate organisms nearly doubled during that period. Around 200 new species have been described for mollusks over the past 15 years. Scientists studying ostracods, bryozoans, ascidians, and polychaetes have described tens of new species.

Questioning of leading specialists allowed me to obtain approximate data on the possible number of all invertebrate species inhabiting the Far Eastern seas. It appears that in this area, one can expect to find more than 9,000 invertebrate species. More than 3,000 species of marine organisms or 34% of the entire fauna of the Far Eastern seas remain unknown. A part of these species, no doubt, will be new to science. Different groups have been studied to varying extents; 80 to 90% of some groups of invertebrates have been studied; these include sponges, hydroids, mollusks, decapods, echinoderms, etc. Only 8-10% of nematodes, 30% of turbellarians, and 40% of scyphozoa have been studied.

I would like to note that, considering the great diversity of fauna in the North Pacific, close cooperation is needed in this field among Russian institutions and on the international level, in particular with scientists from North America. Only joint efforts will attain considerable progress in studying patterns of biodiversity.

In this connection I consider a series of short nearshore NaGISA transects around the Bering Sea to be very important. This region of the junction of Asian and American fauna is needed to understand the origin and distribution patterns of fauna in the whole north Pacific Ocean. Preliminary investigations of species composition and distribution of the rather small and mainly shallow water group Polyplacophora, or chitons, shows an interesting peculiarity. There are 31 species of chitons in the shelf fauna of the Aleutian Islands and the eastern Bering Sea, while only 18 species occur in the shelf fauna of the Commander Islands and eastern Kamchatka. Moreover, 16 species are common for the both regions. We can say that the chiton fauna of the Commander Islands and eastern Kamchatka is impoverished compared to the Aleutian Islands and eastern Bering Sea. However, chitons are principally warm water animals. It would be interesting to compare the fauna of other non-warm water groups of plants and animals.

According to the data collected by an expedition of the Zoological Institute in 1975 to eastern Kamchatka and the expeditions of the Kamchatka Institute of Ecology and Natural Management in 1986 and 1987 to the Bering Islands, the dominant species in both areas are rather similar. About half of the dominant algal and animal species are common for both regions. They consist of the algal genera *Laminaria, Alaria, Thalassiophyllum, Agarum, Neoptilota*, and *Lithothamnion*, barnacles of the genus *Semibalanus*, and sea urchins of genus *Strongylocentrotus*.

My own underwater observations in 1973, 1977, and 1990 from east Kamchatka and the Commander Islands and in 1988, 1999, and 2000 from the eastern Aleutian Islands near Dutch Harbor showed much similarity in species composition of the dominant species. These observations showed that the Aleutian fauna is more diverse than the fauna of east Kamchatka and the Commander Islands. It would be interesting to compare present day data with the historical data obtained in 1975 (near east Kamchatka and in 1972, 1973, 1986, 1991, and 1992 near the Commander Islands).

Biodiversity of the Commander Islands and Bering Sea Coast of the Kamchatka Peninsula by Russian Scientists

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Since the eighteenth century naturalists have rather accurately studied the terrestrial fauna and flora of the Commander Islands and Kamchatka Peninsula. However, hydrobiological studies have only been carried out periodically since the 1930s in the southern part of the Pacific coast (Gur'yanova 1930, Tarakanova 1964, Spasskii 1964, etc.). Unfortunately, a portion of these collections was lost. Another portion was worked up and deposited in the collections of the Zoological Institute and Botanical Institute of the Russian Academy of Sciences. Taxonomists have used these samples for systematic reviews but from a biocenological point of view, these samples were discussed only in one popular paper (Gur'yanova 1935).

Detailed research of the intertidal and sublittoral zones around the Commander Islands and some areas of the Bering Sea coast of Kamchatka began in the 1970s-1980s. Modern hydrobiological methods and scuba were used for studying benthic intertidal and subtidal communities. Different areas of the Mednyi and Bering islands, and the gulfs of Karaginskiy and Olutorskiy of the Bering Sea coast have examined sampling areas of between 100 cm^2 and 1 m^2. A number of standard hydrobiological sections have been performed; hundreds of qualitative and quantitative macrobenthos samples and some thousands of herbarium sheets of various groups of algae were collected (Fig. 1). Samples were sorted into taxonomic groups, organisms counted and weight (blotted on filter paper) determined within 10 mg. Samples were preserved in 75% alcohol or 4% seawater formalin solution. Species lists of intertidal algae and animals summarized from different collections were published in 1978. A total of 121 species of algae and 308 species of animals were reported for

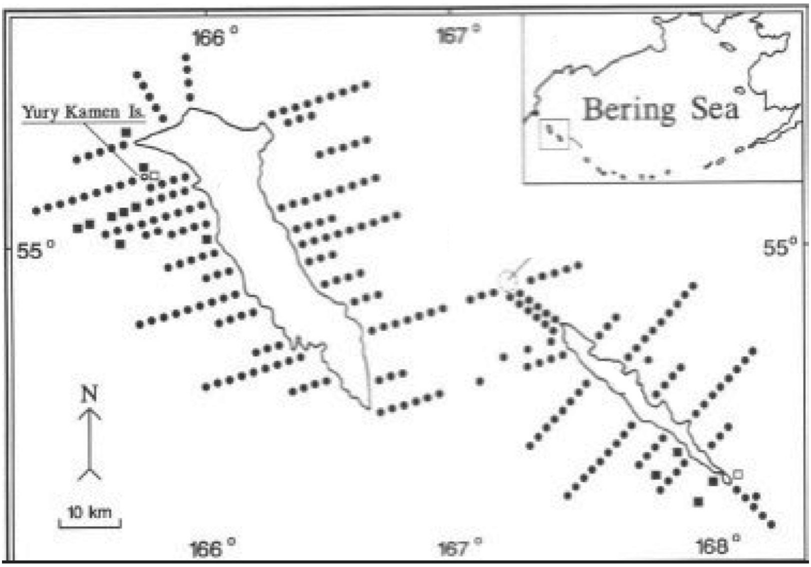

Figure 1. Schematized map of Commander Islands. Intertidal points, subtidal transects, and scuba diving stations are designated.

the Commander Islands and the gulfs of Olutorskiy and Karaginskiy (Kusakin 1978, Vinogradova et al. 1978).

The intertidal of the Commander Islands has been investigated in reasonable detail. There is a description of the intertidal zonation and composition of belt-forming communities of the Mednyi and Bering islands. The population density, biomass, species diversity, and trophic structure of various low-, mid-, and high-intertidal communities have been described. In general, a high species richness of macrophytes and zoobenthos in the littoral zone has been established: 263 species for the Kamchatka coast, 163 species for Mednyi Island, and 145 species for Bering Island (Tarakanova 1978, Kusakin and Ivanova 1995).

Between 11 and up to 29 belt-forming communities were described for different areas of the Bering Sea coast of Kamchatka and the Commander Islands, all of which are distinguished by different dominant species of macrophytes and invertebrates. Within the kelp zone of Mednyi Island, 47 species of macroalgae and 116 species of macrobenthic animals were found; this does not include some species of actinians, nemerteans, and ascidians that are still unidentified. With respect to species richness and diversity, polychaetes (35 species), red algae (24), brown algae (17), gastropods (20), amphipods (19), and bivalve mollusks (12 species) ranked highest (Fig. 2). The biomass of the belt-forming algae amounted to 36 kg per m^2 for *Laminaria longipes*, 22 kg per m^2 for *L. yezoensis*, 15.9 kg per m^2 for *L. bongardiana*, 26 kg per m^2 for *Alaria angusta,* 12.6 kg per m^2 for *A. fistulosa,* and 15.9 kg per m^2 for *Cymathere triplicata*. Among invertebrates the greatest biomass was recorded for the sponge *Halichondria panicea* (4.8 g per m^2, Kusakin and Ivanova 1995) (Fig. 3).

A similar picture of intertidal species richness and diversity was observed on Bering Island. The dominant macrophytes were *Laminaria bongardiana, Fucus evanescens,* and, among invertebrates, the barnacle *Balanus cariosus* and the hermit crab *Pagurus hirsutiusculus*. In some places, the biomass of the sea urchin *Strongylocentrotus polyacanthus* exceeded six times the biomass of seaweed in the community zone of *Ulva fenestrata* and *Bossiella cretacea* (Tarakanova 1978).

More than 20 community types were described from 14 study sites along the intertidal of the Bering Sea coast of the Kamchatka Peninsula. They were characterized by the dominance of the brown algae *Laminaria bongardiana, Fucus evanescens* and other associated algal and animal species similar to those on the Commander Islands (Kusakin, Ivanova 2002).

Some floral and faunal groups in the shallow subtidal of the Commander Islands have been investigated (Fig. 4). A total of 648 species were recorded, almost 25% of them being macroalgae (Sheiko and Stepanjans 1997). Detailed data on species composition, ecology, and distribution have been given for macrophytes (150 species), sponges (47), hydrozoans (52), nemerteans (17), polychaetes (125), bryozoans (141), chitons (18), bivalves (20), gastropods (29), and decapods (25 species).

The collections from three hydrobiological expeditions (1972, 1973, 1993) to the Commander Islands shelf were specifically analyzed for bivalve mollusks. Sixty-three species, 30 of which were new records for this region, have been found. Bivalve species composition was analyzed by depth strata: intertidal zone—20 m, 40-80 m, and 100-300 m—and species composition was found to be determined by the substrate type specific to these depths. A comparative similarity analysis of the bivalve fauna of the Commander Islands shelf with the bivalve fauna of other North Pacific regions shows that the Commander Islands bivalve composition is most similar to Kamchatka (Fig. 5) and the least similar to the Aleutian Islands and Alaska (Kamenev 1995). At the same time, there is one species of prickleback, *Alectridium aurantiacum,* which is common in the intertidal for both the Commander and Aleutian islands (Balanov et al. 1999).

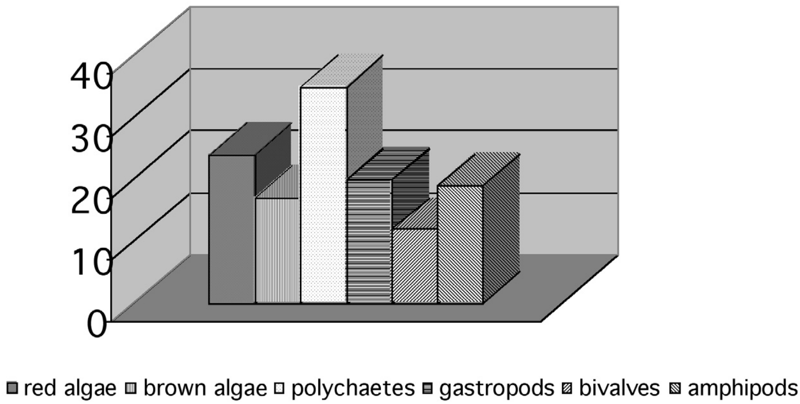

Figure 2. Community of laminarian algae. Species richness of the Mednyi Island intertidal.

Figure 3. Community of laminarian algae. Algal biomass at Mednyi Island.

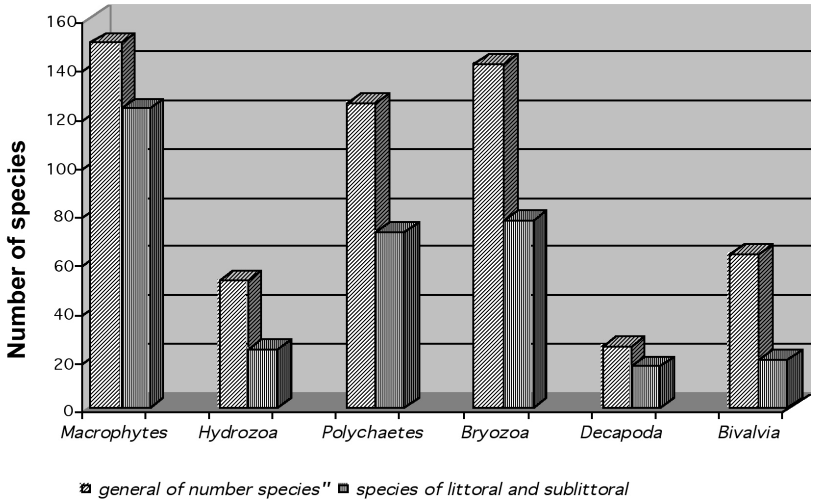

Figure 4. Species richness of shallow waters of the Commander Islands.

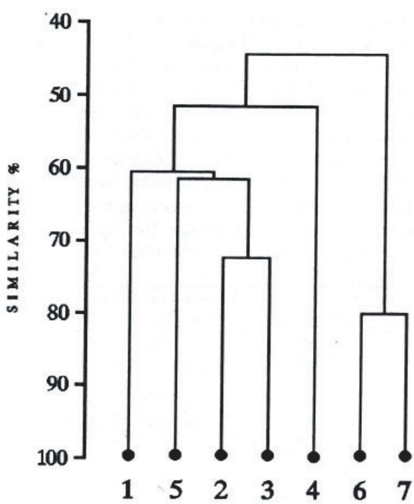

Figure 5. Dendrogram of similarity of bivalve species composition for the seven North Pacific shelf zone regions. 1 = Kurile Islands; 2 = Pacific coast of Kamchatka; 3 = southwestern Bering Sea; 4 = Anadyr Bay; 5 = Commander Islands; 6 = Aleutian Islands; 7 = Bering coast of Alaska (by Kamenev 1995).

At present it is impossible to perform a detailed comparison of the composition and structure of the intertidal communities of the Commander Islands and the Aleutian Islands due to the lack of detailed description of the intertidal biota of the latter. However, judging from the species lists of common algae of the subtidal fringe, many belt-forming species seem to be common for both the Mednyi Islands and the Aleutian Islands. These are *Laminaria longipes, L. yezoensis, Thalassiophyllum clathrus, Odonthalia floccosa,* and others (Estes et al. 1978, Dethier and Diggins 1988, Simenstad et al. 1978, Kusakin and Ivanova 1995). Among the most abundant species of invertebrates mentioned by these authors for the lower intertidal zone and subtidal fringe of the Aleutian Islands are *Strongylocentrotus polyacanthus, Cryptochiton stelleri, Collisella pelta, Leptasterias alaskensis,* and some others that are also typical for the Commander Islands. However, the chiton *Katharina tunicata* that is common in the coastal waters of the Aleutian Islands, including the western ones, is not found on the Commander Islands.

The scientists who worked on the Commander Islands during the last century mentioned the occurrence of the large laminarian algae *Nereocystis luetkeana* and *Hedophyllum sessile* among the common species. The former one was so abundant in the upper subtidal zone and in the infra-littoral fringe that, according to Grebnitskii, it was very difficult for a boat to move through the thickets of this alga (Zinova 1940). Kardakova-Prezhentsova (1938), who worked on the Commander Islands (including Mednyi Island), mentioned that this species often washed ashore during winter, and that the local inhabitants made ropes and lines for halibut fishing out of its trunk-like stipe and used the floats of the alga for some small odd jobs. According to their data, *Hedophyllum sessile,* together with *Alaria angusta* and *Fucus evanescens,* formed dense mats on stones and dried during low tides, and these algae were used to feed cattle and polar fox. However, neither Tarakanova in 1964 nor the authors of this paper in 1972 and 1993 encountered these algae on the coast of the Commander Islands. Only single dried floats of *N. luetkeana* were occasionally found on the beach. As another testimony of change in species ranges, the American isopod species *Idotea* (*Pentidotea*) *wosnesenskii* was found in the rocky mid-intertidal zone of Mednyi and Toporkova islands in great abundance in 1993. This species had never been found on the Commander Islands before, at least not before 1972 (Kusakin and Ivanova 1995).

Long-term studies, which have continued for at least a century in the coastal waters of the Commander Islands by naturalists and later, hydrobiologists, have shown the existence of a continuous exchange of some floristic and faunistic elements between the Commander and Aleutian islands. In such an exchange, the role of the Mednyi Islands, which are closest to the Aleutian ridge, is especially significant. It is interesting that, despite insignificant differences between the hydrological regimes of the Commander Islands and the western Aleutian Islands, the existing exchange of species seems to be limited and undergoing considerable fluctuations.

At the same time, the data on the collections of many invertebrate groups (soft and gorgonian corals, gastropods, ostracods, polychaetes, etc.) remain unpublished and also sorted only into larger taxonomic groups. The biodiversity of the Kamchatka coast remains poorly investigated. The information on these regions sometimes has fragmentary character and is scattered among various reviews on oceanographic regions or taxonomic groups.

The Institute of Marine Biology has highly skilled marine biologists and taxonomists with experience working in various areas of the world's oceans. The institute also provides a diving service with professional divers. Marine operations of the Far East Branch of the Russian Academy of Science has various research vessels without restriction of areas of navigation with laboratories for 25-38 scientists. Employees of the institute perform sampling and processing of intertidal and sublittoral samples. They can provide taxonomic identification of the following groups: Amphipoda, Decapoda, Isopoda, Echiurida, Foraminifera, Gastropoda, fishes, Hydroidea, Mollusca, Ostracoda, Polychaeta, Priapulida, and Sipuncula. Meiobenthos can be sorted into major groups.

It is evident that it could be of considerable interest to execute a detailed comparative hydrobiological survey of the intertidal and sublittoral zones of the Commander-Aleutian arch at the present conditions. Areas of special interest for such a comparison would be Gladkovskaya Bay and Korabelnaya Bay (Mednyi Island), Buyan Bay and Cape Tolstyi (Bering Island), and the area of Cape Africa (coast of Kamchatka).

References

Balanov, A.A., A. Kunio, and T.W. Pietsch. 1999. Redescription and first record of the prickleback fish *Alectridium aurantiacum* (Perciformes: Stichaedae) from the central Kuril Islands. Species Diversity 4:389-396.

1997. Benthic flora and fauna of the shelf zone of the Commander Islands. Dalnauka, Vladivostok. 270 pp.

Estes, J.A., N.S. Smith, and J.F. Palmisano. 1978. Sea otter predation and community organization in the western Aleutian Islands, Alaska. Ecology 59: 822-833.

Dethier, M.N., and D.O. Duggins. 1988. Variation in strong interaction in the intertidal zone along a geographical gradient: A Washington-Alaska comparison. Mar. Ecol. Progr. Ser. 50:97-105.

Kordakova-Prezehentsova, E.A. 1938. Algal vegetation of the Commander Islands. Izv. TINRO 14:77-108.

Kamenev, G.M. 1995. Species composition and distribution of bivalve Mollusca on the Commander Islands shelf. Malacol. Rev. 28:1-23.

Kusakin, O.G. 1978. List of animals of the intertidal zone of eastern Kamchatka and western coast of the Bering Sea. In: Litoral' Beringova Morya i Yugo-Vostochnoi Kamchatki (Intertidal zone of the Bering Sea and southeastern Kamchatka). Nauka, Moscow, pp. 157-173.

Kusakin, O.G. 1995. A recent invader to the Commander Islands: A common northeast Pacific *Idotea wosnesenskii*. Russ. J. Mar. Bio. 20:97-99.

Kusakin, O.G., and M.B. Ivanova. 1995. Macrobenthos of intertidal communities of Mednyi Island, the Commander Islands. Russ. J. Mar. Bio. 21:80-88.

Kusakin, O.G., and M.B. Ivanova. 2002. Species composition, distribution and the quantitative characteristic of a macrobenthos of an intertidal Bering Sea coast Kamchatka (gulfs of Karaginskiy and Olutorskiy). State of pelagic and benthic communities and their environments in the Far Eastern seas at the border of XX and XXI centuries. Izvestiya Pac. Res. Fish. Centre 130:266-296.

Oshurkov, V.V., and E.A. Ivanjushina. 1993. Effect of experimental harvesting on kelp regrowth and on the structure of the shallow water communities of Bering Island (Commander Islands). Asian Mar. Biol. 10:95-108.

Selivanova, O.N., and G.G. Zhingadlova. 1997. Macrophytes of the Commander Islands. In: Benthic flora and fauna of the shelf of the Commander Islands. Dalnauka, Vladivostok, pp. 11-58.

Sheiko, O.V., and S.D. Stepanjans. 1997. Hydrozoans of the Commander Islands shelf zone. In: Benthic flora and fauna of the shelf of the Commander Islands. Dalnauka, Vladivostok, pp. 71-108.

Simenstad, Ch.A., J.A. Estes, and K.W. Kenyon. 1978. Aleuts, sea otters and alternate stable-state communities. Science 200:403-411.

Tarakanova, T.F. 1978. Qualitative distribution of macrobenthos in the intertidal zone of Bering Island. In: Litoral' Beringova Morya i Yugo-Vostochnoi Kamchatki (Intertidal zone of the Bering Sea and southeastern Kamchatka). Nauka, Moscow, pp. 63-77.

Zinova, E.S. 1940. Marine algae of the Commander Islands. Trudy Tikhookean. Komiteta. 5:165-243.

Arctic Benthic Diversity: Deep-Sea Meiofauna and Shelf Macrofauna

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Summary

Biological diversity can be examined at different spatial scales: within community (α diversity), between communities (β diversity), and regional (γ diversity) (Whittaker 1975). Most studies compare within community diversity or diversity between communities along an environmental gradient (e.g., depth, productivity), though regional diversity gives greater insight into evolutionary and biogeographic patterns. Biodiversity research examines patterns of biological diversity revealed by these measures of diversity to ask three main questions (Lambshead 1993): (1) what species are present in an area and where are they found? (2) what are the processes causing extinctions and speciation over evolutionary time scales? and (3) what processes control diversity over ecological time scales? My contribution largely compares within community diversity of meiofauna and macrofauna from along a transect in the central Arctic Ocean and among areas on the northeast Greenland Shelf in the Northeast Water Polynya.

The abundance of the meiobenthos and the biomass and community structure of the nematodes in the central Arctic Ocean along two transects, sampled in 1991 and 1992, were investigated by Vanreusel et al. (2000). Meiobenthic densities were on the same order as other oligotrophic areas of the world's deep oceans (<100-600 individuals per 10 cm^2) and nematodes were the numerical dominant meiofaunal group (94%) of the 19 different taxa collected. Water depth and latitude explained 67% and 55% respectively of the variability in nematode biomass, suggesting that both vertical and advective fluxes of organic material are important sources of food to the meiobenthos. In the paper, we used multivariate analyses of nematode genera to reveal differences among stations in the Eurasian and Amerasian basins.

We did not, however, examine patterns of diversity in nematode genera beyond reporting the number of genera found (50 in 1991, and 111 in 1994 of which 41 were also found in 1991). A genus accumulation curve across all samples shows no indication of reaching an asymptote, indicating that the diversity of nematode genera from the central Arctic Basin is in excess of 120 genera.

I used three measures of within community diversity to compare the diversity of meiobenthos among locations across the Arctic Basin. Rarefaction curves revealed large differences in the diversity of nematode genera among stations, $EG_{(125)}$ varied between 11 and 31, but there were no clear patterns. The Amerasian Basin had a greater number of meiofauna taxa (6.4) and nematode genera (29) compared to the Lomonosov Ridge (5.0 and 24.4) and the Eurasian Basin (4.5 and 23.5), but the differences were not significant. Rarefaction curves and K-dominance curves of nematode genera also revealed no differences in diversity among these areas. The Shannon diversity index was also not different between the basins and the Lomonosov Ridge and was not related to water depth or latitude.

Nematode diversity in the central Arctic Ocean appears to be greater than in the Laptev Sea (Vanaverbeke et al. 1997), the one other study of Arctic meiobenthos that identified nematodes (but see Pfannkuche and Thiel 1987). This pattern agrees with the pattern of greater diversity of nematodes from abyssal and bathyl depths in temperate and tropical areas compared to sublittoral and estuarine habitats (Boucher and Lambshead 1995). The diversity of nematodes at similar depths in Antarctica (Weddell Sea) is much greater than we found in the Arctic Ocean. The estimated number of nematode genera from 100 individuals was 1.5 to 2 times greater in the Weddell Sea than in the Arctic Basin and the highest Shannon Index was 3.4 in the Arctic compared to 5.6 in the Antarctic (Vanhove et al. 1999).

Macrofauna (collected on a 250 μm sieve) were collected at the same stations as meiofauna on the 1994 transect. Except for polychaetes, which were identified to family, other taxa were only identified to phylum (nemerteans, sipunculids), class (mollusks), or order (crustacean). Density was low compared to other deep-sea areas, ranging from 141 to 6,878 individuals per m^2 for metazoans with as many as an additional 5,456 Foraminifera per m^2. Biomass ranged from 1.7 to 522 mg C/m^2 with up to 96% accounted for by the Foraminifera. The number of taxa collected exceeded 40 and there was no indication that number of new taxa collected was declining with increasing sampling. The number of taxa collected was similar to the number collected by Kröncke (1998) in the Amundsen Basin and Yermak Plateau and Deubel (2000) in the Eurasian Basin and along the Lomonosov Ridge, but fewer by 50% than the number Kröncke

(1994) collected along a transect from Svalbard to the Makarov Basin. The mean number of taxa per station was significantly greater in the Amerasian Basin (11.3) compared to the Eurasian Basin (5.0) with the number of taxa per station on the Lomonosov Ridge intermediate (7.3). There was no significant difference in the Shannon diversity index among these areas. There was a significant relationship between the number of taxa and both water depth and latitude suggesting that differences between the Amerasian Basin and the Eurasian Basin are due to the deeper depths of the Eurasian Basin stations and its covariate greater distance from the shelf break.

It is difficult to draw any conclusions about the diversity of meiofauna and macrofauna in the central Arctic Basin because so few studies have been conducted in this area. Density and biomass are low as is to be expected for the oligotrophic deep sea. There are differences in community composition and species diversity across the Arctic Basin and the limited data on these communities suggest that organic input, controlled by water depth, distance from shore, and topography, is the most significant factor in explaining patterns (Kröncke 1994, Vanreusel et al. 2000, Deubel 2000).

The Northeast Water Polynya (NEW) is a recurrent annual feature of variable size on the northeast Greenland Shelf. The area is characterized by complex bathymetry: very shallow banks (water depth <40-150 m), separated by a trough system (Belgica Trough in the South and West Wind Trough in the north with water depths of 250 to >500 m). Total abundances of nematodes, polychaetes, and peracarid crustaceans are primarily related to parameters characterizing organic input to the benthos (water column and benthic pigments) while abundances of Foraminifera and megabenthos are largely associated with sediment grain size and bottom water temperature (Piepenburg et al. 1997). Multivariate analysis of polychaete families clearly distinguishes two areas of the northern trough (east and west) and the southern trough as having distinct community composition, with stations from the shallower banks less differentiated. Patterns of benthic diversity in the NEW polynya have not been previously examined.

Over 150 polychaete species were identified from replicate (4-5) cores (0.005 m^2) from 28 stations with no indication that the sampling effort had been sufficient to collect all the species present. The southern trough had significantly fewer polychaete species per sample (14.7) compared to stations from the northern trough (23.4) or central bank (25.7). But infaunal densities are also significantly lower in the southern trough compared to other areas in the polynya (Ambrose and Renaud 1995), biasing any comparison of just species richness. The Shannon diversity index and rarefaction curves confirmed the lower diversity in the southern trough compared to the bank and northern trough. The southern trough has greater ice cover than the central bank and northern trough which open earlier in the season, so it is tempting to explain the lower polychaete diversity in the south compared to the north by differences in water column productivity between these areas. Both polychaete species richness and the Shannon diversity index are negatively correlated with grain size (Φ), however, and stations in the southern trough have a finer sediment (greater Φ) and greater depth than other areas sampled.

A comparison of β diversity between the trough stations and stations on the bank indicates that northern and southern troughs are more similar to each other than to the bank. But the Bray-Curtis similarity index shows only a 33% similarity in the polychaete fauna between troughs, which are only 17% similar to bank stations. The lack of similarity, particularly between troughs with similar water depths and sediment grain size, indicates the need to sample across habitats and at large spatial scales if we hope to examine regional diversity across the Arctic.

More studies of benthic diversity have been conducted on Arctic shelves than in the Arctic Basin. As early as 40 years ago, Zenkevich (1963) estimated there were 1,600 species in the Barents Sea and over 2,000 in the Western Bering Sea (of which 80% are probably benthic taxa, Curtis 1975) while he records only 363 benthic species from the Laptev Sea. While species richness appears to be low in the Laptev and Beaufort seas relative to other shelf areas (Curtis 1975), there appears to be remarkable similarity in diversity on Arctic shelves from the Chukchi Sea to the Barents Sea (Stewart et al. 1985, Grebmeier et al. 1989, Kendall and Aschan 1993, Kendall 1996, Sejr et al. 2000). The estimated number of species for 201 individuals collected ranges from 28 in a Svalbard fjord to 52 in a Greenland fjord with both the lowest (1.0) and highest (5.9) Shannon index recorded from stations in Davis Strait. Most shelf areas, however, have an $ES_{(201)}$ of 35-40 and a Shannon index of 2-3.

Arctic benthic communities do not appear to be impoverished compared to communities on shelves at lower latitudes. A comparison of diversity from the Svalbard Shelf and a fjord on the west coast of Svalbard with lower latitude locations of similar depth and grain size indicates these assemblages are equal in diversity to samples collected from the North Sea and Java (Kendall and Aschan 1993, Kendall 1996). There appears to be no latitudinal gradient in the diversity of infauna on continental shelves.

Most studies of benthic diversity concentrate on the infauna and there have been few studies examining the distribution, abundance, and diversity of epifaunal organisms and all of these studies have been conducted on shelves. Megabenthos in general and epifaunal organisms in particular are not sampled quantitatively with the grabs and cores typically used to sample benthic communities. Photography, either still or video, have proven more successful than core or grab sampling at quantifying the abundance and diversity of epibenthic communities. The epibenthos on Arctic shelves is dominated by echinoderms (see Piepenburg 2000 for review, Ambrose et al. 2001) where densities and biomass of ophiuroids alone can reach 250 individuals per m^2 and 5,000 mg C/m^2 (Ambrose et al. 2001). Piepenburg has conducted photographic surveys of epibenthic fauna around Svalbard (Piepenburg et al. 1996), on the east Greenland Shelf (Piepenburg and Schmid 1996a), in the Laptev Sea (Piepenburg and Schmid 1997), in the Barents Sea (Piepenburg and Schmid 1996b) and north of Iceland (Piepenburg and Juterzenka 1994). These studies and Ambrose et al. (2001) indicate that bottom topography, grain size and hydrography are the most important factors controlling the structure of megabenthic communities on Arctic shelves. A systematic comparison of the epibenthos from Arctic shelves has not been made, but the abundance of echinoderms alone in the Chukchi Sea is the highest recorded on any shelf (Ambrose et al. 2001). In addition, ROV footage from the head of Barrow Canyon suggests that areas with high flux of organic material and diverse bed forms promise to support high epibenthic biomass and diversity.

Clearly more systematic studies of benthic diversity in the Arctic need to be conducted. Our knowledge of the distribution, abundance, and diversity of benthic communities in the central Arctic Basin is particularly inadequate. But even the more numerous studies on Arctic shelves have been concentrated in very few areas. In these areas polychaetes dominate the macrofauna and have received the most attention. Foraminifera often dominate macrofaunal samples from the deep sea, and are common in shelf samples but their patterns of diversity have not been adequately explored (Ahrens et al. 1997, Wollenburg and Kuhnt 2000). There have been only three studies (Vanaverbeke et al. 1997, Pfannkuche and Thiel 1987, Vanreusel et al. 2000) of meiofauna from the Arctic Basin with few samples taken from Arctic shelves (Pfannkuche and Thiel 1987). Furthermore, only one study (Piepenburg et al. 1997) has quantified distribution and abundance patterns of different fractions of the benthos ranging in size over 6 orders of magnitude (from 100 μm for meiofauna to 10 cm for epibenthos). These limited data suggest that the diversity on Arctic shelves is similar to shelves in temperate and even tropical areas, while deep-sea communities in the Arctic are impoverished even when compared to Antarctic communities.

Many of the studies examining biodiversity of the benthos were conducted as part of projects designed to address questions other than biodiversity. Consequently, sampling strategies were not optimized to quantify the diversity of habitats or regions. It is critical to design sampling programs specifically to investigate diversity and not expect to collect useful diversity data as an afterthought to a sampling program designed for other purposes. In order to obtain the spatial coverage necessary to address patterns of regional diversity, it may be necessary to sacrifice finer scale patterns of diversity and some replication. Samples should be collected at a variety of spatial scales along gradients in depth, organic input, and bottom topography using methods to sample the full range of benthic taxa if we are to document and understand local and regional patterns of species diversity in the Arctic.

References

Ambrose Jr., W.G., and P.E. Renaud. 1995. Benthic response to water column productivity patterns: Evidence for benthic-pelagic coupling in the northeast water polynya. J. Geo. Res. 100:4411-4421.

Ambrose Jr., W.G., L.M. Clough, P.R. Tilney, and L. Beer. 2001. Role of echinoderms in benthic remineralization in the Chukchi Sea. Mar. Biol. 139: 937-949.

Ahrens, M.J., G. Graf, and A.V. Altenbach. 1997. Spatial and temporal distribution patterns of benthic Foraminifera in the Northeast Water Polynya, Greenland. J. Mar. Syst. 10:445-465.

Boucher, G., and P.J.D. Lambshead. 1995. Ecological biodiversity of marine nematodes in samples from temperate, tropical and deep-sea regions. Conserv. Biol. 9:1594-1604.

Curtis, M.A. 1975. The marine benthos of arctic and sub-arctic continental shelves. Polar. Rec. 17:595-625.

Deubel, H. 2000. Structures and nutrition requirements of macrozoobenthic communities in the areas of the Lomonossov Ridge in the Arctic Ocean. Ber Polarforsch. 370.

Grebmeier, J.M., H.M. Feder, and C.P. McRoy. 1989. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi seas. II. Benthic community structure. Mar. Ecol. Prog. Ser. 51:253-268.

Lambshead, P.J.D. 1993. Recent developments in marine benthic biodiversity research. Océanis 19:5-24.

Kendall, M.A. 1996. Are arctic soft-sediment macrobenthic communities impoverished? Polar Rec. 16:393-399.

Kendall, M.A., and M. Aschan. 1993. Latitudinal gradients in the structure of macrobenthic communities: A comparison of arctic, temperate and tropical sites. J. Exp. Mar. Biol. Ecol. 172:157-169.

Kröncke, I. 1994. Macrobenthos composition, abundance and biomass in the Arctic Ocean along a transect between Svalbard and the Makarov Basin. Polar Biol. 14:519-529.

Kröncke, I. 1998. Macrofauna communities in the Amundsen Basin, at the Morris Jesup Rise and the Yermak Plateau (Eurasian Arctic Ocean). Polar Biol. 19:383-392.

Pfannkuche, O., and H. Thiel. 1987. Meiobenthic stocks and benthic activity on the NE-Svalbard Shelf and in the Nansen Basin. Polar Biol. 7:253-266.

Piepenburg, D., and K. von Juterzenka. 1994. Abundance, biomass and spatial distribution patterns of brittle stars (Echinodermata: Ophiuroidea) on the Kolbeinsey Ridge north of Iceland. Polar Biol. 14:185-194.

Piepenburg, D., and M.K. Schmidt. 1996a. Distribution, abundance, biomass, and mineralization potential of the epibenthic megafauna of the northeast Greenland Shelf. Mar. Biol. 125:321-332.

Piepenburg, D., and M.K. Schmidt. 1996b. Brittle star fauna (Echinodermata: Ophiuroidea) of the arctic northwestern Barents Sea: Composition, abundance, biomass and spatial distribution. Polar Biol. 16:383-392.

Piepenburg, D., and M.K. Schmidt. 1997. A photographic survey of the epibenthos megafauna of the Arctic Laptev Sea shelf: Distribution, abundance, and estimates of biomass and organic carbon demand. Mar. Ecol. Prog. Ser. 147:63-75.

Piepenburg, D., N.V. Chernova, C.F. von Dorrient, J. Gull, A.V. Neyelov, E. Rachor, L. Saldanha, and M.K. Schmid. Megabenthic communities in the water around Svalbard. Polar Biol. 16:431-446.

Piepenburg, D., W.G. Ambrose Jr., A. Brandt, P.E. Renaud, M.J. Ahrens, and P. Jensen. 1997. Benthic community patterns reflect water column processes in the Northeast Water polynya (Greenland). J. Mar. Syst. 10:467-482.

Sejr, M.K., K.T. Hense, and S. Rysgaard. 2000. Macrobenthic community structure in a High-Arctic East Greenland Fjord. Polar Biol. 23:792-801.

Stewart. P.L., P. Pocklington, and R. Cuniak. 1985. Distribution, abundance and diversity of benthic macroinvertebrates on the Canadian continental shelf and slope of southern Davis Strait and Ungava Bay. Arctic 38:281-291.

Vanaverbeke, J., P.M. Arbizu, H.-U. Dahms, and H.K. Schminke. 1997. The metazoan meiobenthos along a depth gradient in the Arctic Laptev Sea with special attention to nematode communities. Polar Biol. 18:391-401.

Vanhove, S., W. Arntz, and M. Vinex. 1999. Comparative study of the nematode communities on the southeastern Weddell Sea shelf and slope (Antarctica). Mar. Ecol. Prog. Ser. 181:237-256.

Vanreusel, A., L. Clough, K. Jacobsen, W. Ambrose, J. Jivaluk, V. Ryheul, R. Herman, and M. Vinex. 2000. Meiobenthos of the central Arctic Ocean with special emphasis on the nematode community structure. Deep-Sea Res. 47:1855-1979.

Whittaker, R.H. 1975. Communities and Ecosystems. 2nd edn. MacMillan Press, New York.

Wollenburg, J.E., and W. Kuhnt. 2000. The response of benthic foraminifers to carbon flux and primary production in the Arctic Ocean. Mar. Micropaleontol. 40:189-231.

Zenkevick, L.A. 1963. Biology of the seas of the USSR. Allen and Unwin, London.

Biodiversity in the American Arctic

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What is biodiversity?

Biodiversity is a product of the interactions of life on scales ranging from the smallest, at the chromosome level, to organisms, and ecosystems. There are three general kinds of biodiversity: genetic diversity, species diversity, and habitat diversity. The survival of each is linked to the health of the other two, and together they comprise ecosystems.

Species biodiversity

Species biodiversity is what most people refer to when they discuss biodiversity. Species biodiversity is defined by the kinds and numbers of organisms within a particular region and their pattern of distribution. This discussion will focus on what is known about species biodiversity of the marine habitats of the Alaskan Arctic coastal waters.

History of marine research in the American Arctic

OCSEAP

Prior to 1970, studies of the Arctic coast were limited primarily due to the remoteness of the area and extreme weather conditions. Discovery of oil on the North Slope in 1968 and the subsequent leasing of Beaufort Sea offshore tracts for oil exploration and drilling prompted the U.S. government to sponsor intense baseline studies of the continental shelf surrounding Alaska. The Outer Continental Shelf Environmental Assessment Program (OCSEAP) was established by basic agreement between the U.S. Department of Commerce via the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of the Interior, via the Bureau of Land Management (BLM) and Minerals Management Service (MMS), to conduct environmental research on Alaskan Outer Continental Shelf (OCS) areas identified by the BLM for potential oil and gas development. Teams of scientists from many universities and agencies collected data on physical regimes (ice, currents, salinity, temperature, etc.) and biological ecosystems (phytoplankton, zooplankton, benthos, etc.) for a decade starting in 1975. Participating scientists were required to submit reports that were bound into numerous volumes. A bibliography volume listing all submitted reports was printed in 1990. The most complete set is housed at the University of Alaska Fairbanks.

Other research

Several other programs collected data on Alaskan marine species but all focused on the Bering and Chukchi seas with only a few stations sampling the far western portion of the Beaufort Sea. NSF's Inner Shelf Transfer and Recycling (ISHTAR) cruises took place in the summers of 1985 and 1986 and sampled both the northern Bering and Chukchi seas. A Science of Opportunity (SOO) cruise aboard the USCGC *Polar Sea* sampled the Chukchi and western Beaufort seas during June 1998. The Third (1988) and Fourth (1993) Joint U.S.-USSR Bering and Chukchi Seas Expeditions (BERPAC) sampled the western Chukchi and then traveled into waters adjacent to Russia which were previously inaccessible to U.S. scientists. The Western Arctic Shelf Basin Interactions (SBI) program will collect data in the Chukchi and western Beaufort seas in summer 2002 and 2004. Smaller cruises on the R/Vs *Alpha Helix, Northwind, Glacier, Burton Island,* and *Acona* have taken place over the past 25 years in the Bering and Chukchi seas.

Benthic biomass data

The continental shelf of the Arctic Ocean has proven to be a highly productive zone despite low temperatures and only seasonal pulses of particulate organic matter. In 2000 all known Bering, Chukchi, and Beaufort sea biomass data from 62º north latitude and above were compiled and gathered into a Microsoft Access database. Ken Dunton and Jackie Grebmeier were co-PIs on this project working under Phase I of The Western Arctic Shelf Basin Interactions (SBI) program. The data sources used for this project are listed below.

Benthic biomass data sources

Broad, A.C. 1975-1980. Intertidal organisms and habitat (File 030). National Oceanographic Data Center. Washington, D.C.

Carey, A.G. 1971. WEBSEC-71. Unpublished data.

Carey, A.G., M.A. Boudrias, J.C. Kern, and R.E. Ruff. 1984. Selected ecological studies on continental shelf benthos and sea ice fauna in the southwestern Beaufort Sea. Final Report, Outer Continental Shelf Environmental Assessment Program, Fairbanks, Alaska 23:1-164.

Feder, H.M., R.H. Day, S.C. Jewett, K. McCumby, S. McGee, and S.V. Schonberg. 1982. Infauna of the northeastern Bering and southeastern Chukchi seas. Final Report, Outer Continental Shelf Environmental Assessment Program, Fairbanks, Alaska. 120 pp.

Grebmeier, J.M. 1987. The ecology of benthic carbon cycling in the northern Bering and Chukchi seas. Ph.D. thesis, University of Alaska Fairbanks.

Grebmeier, J.M. 1992. Studies of pelagic-benthic coupling extended onto the Soviet continental shelf in the Bering and Chukchi seas. Continental Shelf Research 13:653-668.

Grebmeier, J.M., and K.H. Dunton. 2000. Benthic processes in the northern Bering/Chukchi seas: Status and global change. In: H.P. Huntington (ed.), Impacts of changes in sea ice and other environmental parameters in the Arctic. Marine Mammal Commission Workshop, Girdwood, Alaska, 15-17 February 2000, pp. 18-93.

Grebmeier, J.M., and L.W. Cooper. 2001. Sediment biogeochemical tracers and carbon cycling in the Bering and Chukchi seas during 1988 and 1993. In: Results of the Fourth Joint US-Russia Bering and Chukchi Seas Expedition (BERPAC), Summer 1993. U.S. Fish and Wildlife Service, Washington, D.C.

Stoker, S. 1978. Benthic invertebrate macrofauna of the eastern continental shelf of the Bering/Chukchi seas. Ph.D. thesis, University of Alaska, Fairbanks. 259 pp.

Wacasey, J.W. 1974. Biological productivity of the southern Beaufort Sea. Zoobenthic Studies. Beaufort Sea Technical Report 12b, Department of the Environment, Victoria, B.C. 39 pp.

Summary of northern continental shelf research compiled for OCSEAP

Feder, H.M. 1979. Bibliography of northern marine waters. Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 6:257 RU 0005.

The purpose of the project was to retrieve benthic biological data from NODC and other published and unpublished data. Geographic Information Systems (GIS) software was used to examine and graphically display the spatial and temporal trends of the benthic data. A bathymetric map was built of the study area and data from six researchers' work on 14 cruises made over a 25 year period (1970-1995). The mean biomass data from 1,093 sites were mapped and examined (Fig. 1). An extension of ArcInfo 8.2, Geospatial Analyst, was used to perform geostatistical methods to determine the spatial and temporal trends of the benthic community. Interpolation of the data (by kriging) was used to predict a surface area between data points because it had the smallest mean error and root-mean-square prediction error and most accurately modeled the data. Application of geostatistical techniques revealed areas of high biomass (>250 gm^{-2}) in the southern Chukchi Sea and in the northwestern Bering Sea, compared to less than 30 gm^{-2} on the Beaufort Sea shelf (Fig. 2). The high benthic biomass in the Bering-Chukchi is coincident with the abundance of benthic feeding marine mammals (e.g., gray whales, walrus) in this region.

Shannon-Wiener Diversity Index

A.C. Broad calculated Shannon-Wiener Index values for each of his benthic sampling stations. The Shannon-Wiener function assumes a random sample is taken from an infinitely large population

$$H' = -\sum_{i=1}^{s} \ln(p_i)$$

p_i = proportion of individuals that belong to species i.
s = number of species in the sample

Higher H' values are associated with greater diversity and a community that is not generally dominated by a few species. Comparison of Figs. 1 and 3 reveals that high biomass and high diversity were not necessarily linked (Fig. 4). On the left (Fig. 4) is a photo of the catch from a trawl in the Chukchi Sea. The biomass is very high but the number of species is low. The right panel shows a photo from the Beaufort Sea Boulder Patch kelp community. The biomass is not extremely high but there are many different species.

Beaufort Sea Boulder Patch

The Boulder Patch deserves special mention because it is a unique area of the Alaskan nearshore with the richest and most diverse biological community known in the American Beaufort Sea (Fig. 5). It is also conveniently located over potentially rich oil and gas reserves. The Alaskan Beaufort Sea shelf is predominantly blanketed by silty sands and mud with faunal assemblages of polychaetes, tiny crustaceans and mollusks. Conversely, the Boulder Patch is characterized by boulders and cobbles which provide a solid substratum for colonization of a large variety of algae and epilithic invertebrates. The

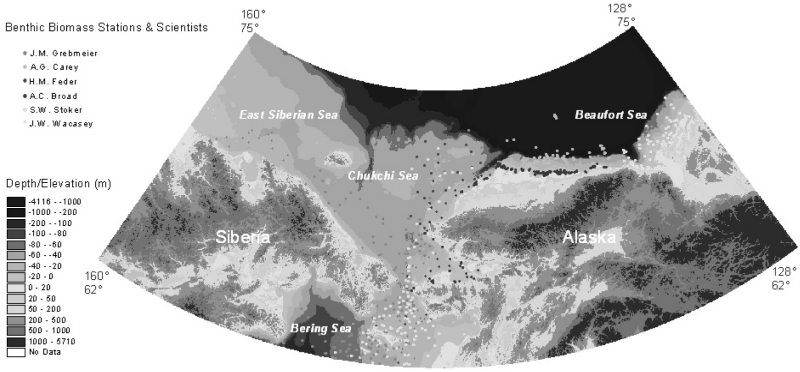

Figure 1. Research station locations on a bathymetric map of the Bering, Chukchi, and Beaufort seas.

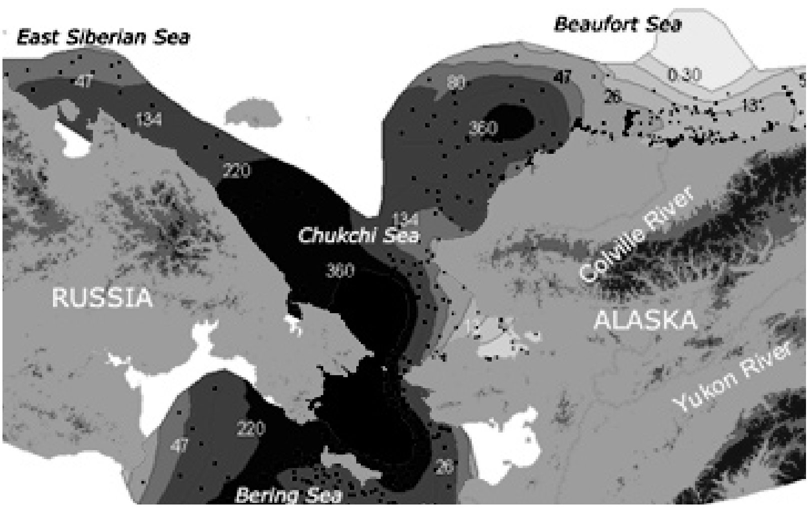

Figure 2. Benthic biomass in the Bering, Chukchi, and Beaufort seas.

Boulder Patch was discovered by marine geologists during summers of 1971 and 1972. Ken Dunton started biological investigations on the diversity and abundance of biota in 1978. Over 160 species representing a variety of invertebrate phyla have been collected from rocks and sediments within the Boulder Patch (Table 1).

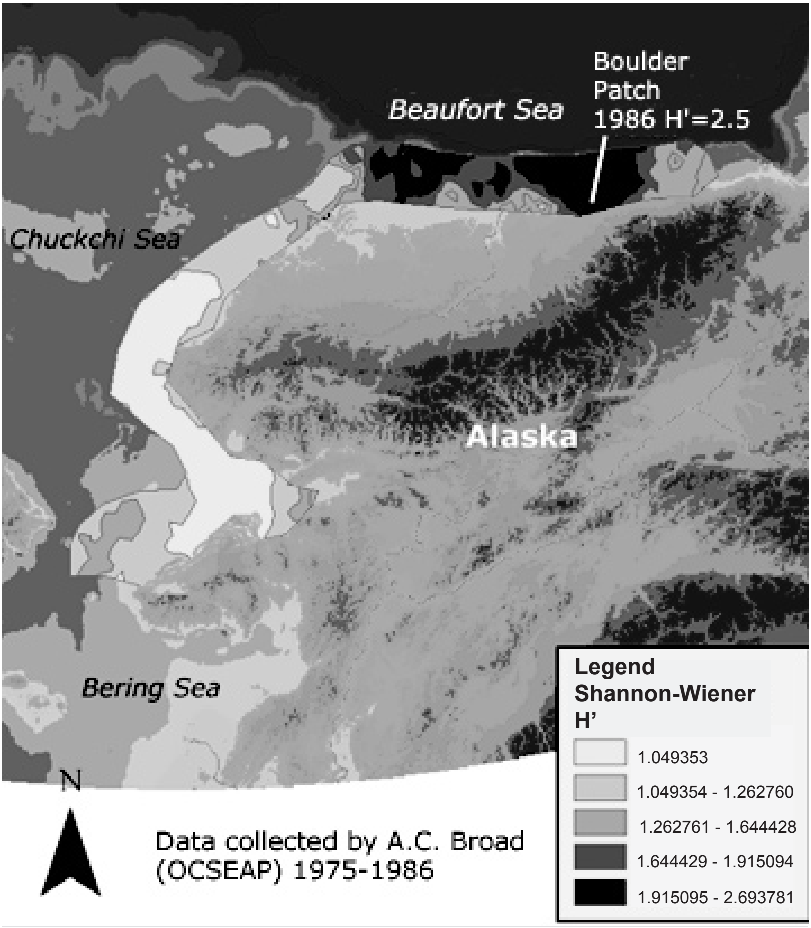

Figure 3. Plot of Shannon-Wiener Diversity Index H' of benthic biomass data.

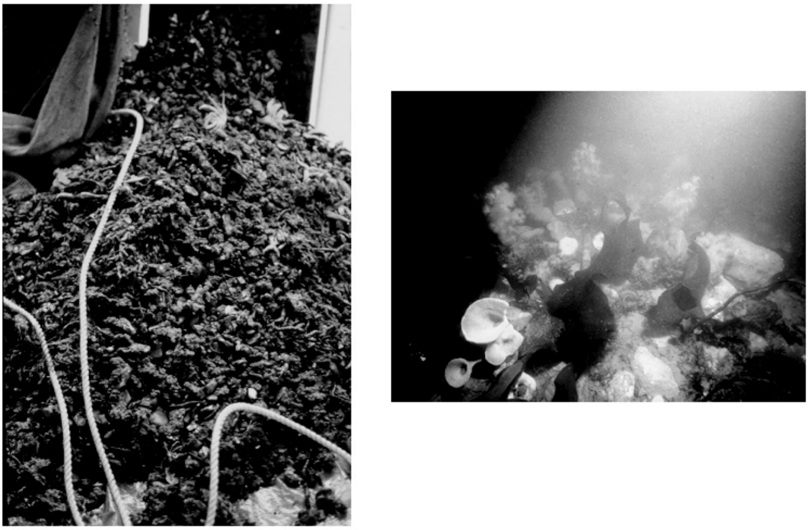

Figure 4. The left photo is the contents of a trawl made in the Chukchi Sea showing high biomass and relatively low diversity. The right photo is of the Beaufort Sea Boulder Patch community with lower biomass but a large number of species.

Table 1. Percentage biomass of biological groups of epilithic and non-epilithic organisms collected between and under rocks in the Boulder Patch.

	Epilithic fauna	Between-rock fauna	Under-rock infauna
Phaeophyta	20%		
Rhodophyta	39%		
Fish	9%		
Porifera	9%	8%	
Polychaeta	3%	15%	7%
Mollusca	7%	34%	6%
Crustacea	1%	7%	6%
Cnidaria	4%	9%	1%
Bryozoa	5%	22%	6%
Ascidacea	2%		
Asteroidea		1%	8%
Foraminifera		2%	1%
Miscellaneous		2%	2%

Figure 5. Location and configuration of the Beaufort Sea Boulder Patch.

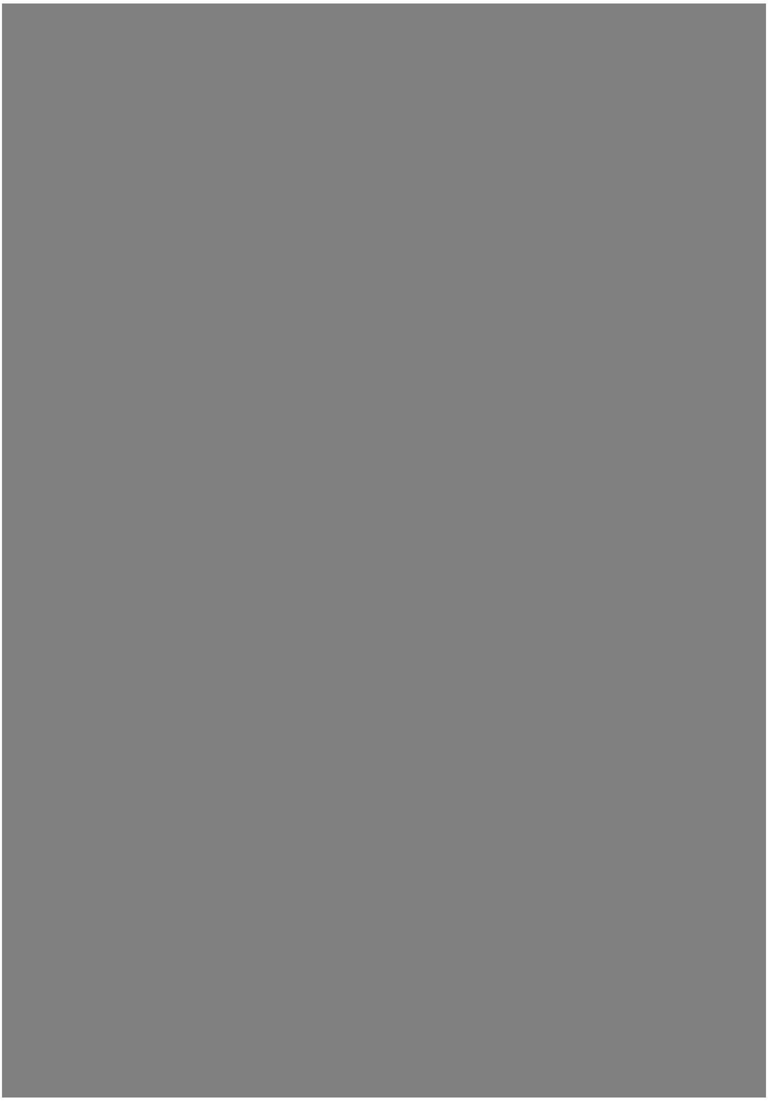

Figure 5. (Continued.) Location and configuration of the Beaufort Sea Boulder Patch.

The Hidden Ocean: Explorations under the Ice of the Western Arctic. A Multidisciplinary Project Funded by the NOAA Ocean Exploration Program

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Life in the crystal palace of sea-ice communities

Sea ice is an important habitat for a wide range of Arctic marine organisms, from bacteria to polar bears. Distinct communities have been observed at the various sub-habitats. The ice surface can be dominated by snow algal communities similar to those from terrestrial annual snowfields; the ice interior is characterized by heterotrophic bacteria and flagellate associations. Diatoms, flagellates, ciliates, nematodes, turbellarians and nauplii dominate the bottom decimeters, and amphipods and copepods frequent the ice-water interface. Bacterial abundances show the lowest vertical variability of all taxa studied so far. Although previous studies demonstrated regional differences of faunal and floral composition in Arctic seas, due to local ice regimes, no attempt has been made so far to assess biodiversity of sea ice biota on a Pan-Arctic transect. Such an undertaking is crucial for the understanding of future changes in the Arctic with observed decreases in ice extent and thickness.

Arctic sea ice exhibits strong regional variability: fast ice differs in its characteristics from the pack ice on the shelves and the deep basins. Algal biomass is varying by about three orders of magnitude with highest values in the coastal and shelf locations. While the shelves have been studied intensively over the last 20 years as part of, e.g., SHEBA, ProMare, SFB 313 and the Laptev Sea project, little progress has been made in the Canada Basin since the Transarctic Transect in 1994. Two recently launched major interdisciplinary research projects (SBI, CASES) contain sea ice components, but the work largely focuses on energy flux on the American/Canadian shelves and the interaction with the deep basins, biomass accumulation and sedimentation patterns. The recent NOAA Ocean Exploration investigation offered the opportunity to collect sea ice samples of offshore Beaufort Sea sea ice. However, the enormous retreat of the pack ice during summer 2002 allowed for only four ice-coring stations, forbidding any basin-wide extrapolations. The combination of ice coring with scuba diving (8 stations) provided the following insights: (a) The pack ice of the Beaufort Gyre is inhabited by sea ice meiofauna, which is comparable with studies from the transpolar drift in terms of abundance and diversity; (b) diver observations and video recordings demonstrated the significance of spatial niches for ice-associated amphipods and *Boreogadus saida*; (c) faunal and floral abundance and biomass on shelf stations in the Chukchi and Beaufort seas were considerably higher than in the Beaufort Gyre, most likely due to the inflow of nutrient rich waters through Bering Strait; (d) some ice meiofaunal taxa might be undescribed species; and (e) the loss of typical ice fauna, as proposed by Melnikov and co-workers based on SHEBA observations, was not observed. These observations lead us to the following recommendations for future ice studies in the High Arctic: (1) A transarctic transect should include shelf regions of the Chukchi and Beaufort seas, extend through the Beaufort Gyre across the transpolar drift, and end (or start) on the Eurasian shelves; (2) such a transect should be augmented by investigations on fast ice systems in various locations (e.g., Amundsen Gulf, Barrow, Franz-Josef-Land); (3) the work should include both ice coring and under-ice diving as tools. The study would benefit from additional sampling of the seasonally ice covered regions of the White Sea, the Sea of Okhotsk and the Baltic Sea, to help identify biogeographical ranges and boundaries.

The pelagic fauna

Knowledge of marine life, especially in the deeper parts of the water, is rudimentary principally because the environment is enormous and alien. Plankton nets, the most universal tool used to obtain samples for over l00 years, capture only a small fraction of the pelagic fauna, primarily the smaller, slower, more robust species. When compared to the more numerous crustaceans like copepods and euphausiids, relatively little is known about ctenophores, siphonophores, hydromedusae, scyphomedusae, pelagic mollusks, and pelagic tunicates in all oceans, but especially in polar seas. The most obvious explanation for this disparity is their extreme fragility. Collection with nets destroys most soft-bodied species or reduces them to fragments. As a result the remaining parts are usually ignored, discarded, misidentified, or simply recorded as "jelly." Not as apparent is the fact that nets commonly used to sample copepods are often too small (≤ 1 m diameter) and fitted with mesh that's too fine (≤ 0.5 mm). Consequently, the volumes of water filtered are inadequate to provide reliable estimates of a more dispersed fauna like the gelatinous zooplankton. Furthermore, conventional preservatives typically dissolve the natural rich iridescent colors of live animals and often liquefy ctenophores. It is, therefore, not surprising that the basic biodiversity as well as the biomass and abundance of gelatinous animals are grossly underestimated.

Descriptions of gelatinous zooplankton from the Arctic Ocean are widely scattered in the published literature. Investigations began in the late 1800s and have continued, sporadically, with much of the work conducted in the European and Russian seas. Presently, the number of species recognized for each group varies depending on the source. The known diversity of the gelatinous groups is as follows: ctenophores (6 species), medusae (45 species), siphonophores (12 species), pteropods (4 species) and larvaceans (5 species). In contrast to the fragile gelatinous zooplankton, knowledge of Arctic cephalopods suffers due to their ability to avoid nets and trawls (only 7 species are known), however, there is a long history of successful observation of this group by ROVs and submersibles. Based on our ROV/submersible experience in other oceans, we expected that at least twice as many species actually exist in each group, probably more. Their ecological importance in the Arctic is poorly known.

Understanding the dynamics of any biological community requires knowledge of diversity, abundance and biomass. We needed to see if a medium-sized "portable ROV," the *Global Explorer*, was up to the task. As a first step, we began to develop an in situ photographic inventory of gelatinous zooplankton in the entire water column, as well as shipboard photography of all live material collected by fine-meshed plankton nets equipped with large-volume cod-ends. The patterns of distribution and density were observed throughout the water column down to 2900 m on 5 dives accruing over 30 hrs of observations. Logistical and mechanical problems greatly limited the number of dives performed and prevented detailed observation or collection. Ten stations were sampled with plankton nets to 500 m depth, with unexpected success. Plankton net collections, videotape, and still images are still being processed, with molecular bar-coding under way for select groups.

Deep-sea benthos diversity and food web structure

Benthic communities in general depend on food supplied from the water column. In high latitudes, the amount of sedimenting food particles rather than the low water temperature per se is restraining growth and survival of Arctic benthic organisms (Clarke 1983, Hebbeln and Wefer 1991). On the shallow North American shelves, particle transport to the benthos from the pelagic realm to the benthos is relatively large over the ice-free period. An impressively high faunal biomass is supported in the areas of the very nutrient-rich and productive Bering Sea–Anadyr water in the northern Bering and Chukchi seas (Grebmeier et al. 1995). However, few of the accessible benthic data in the North American Arctic are from stations deeper than 200 m. Information about slope and deep-sea benthos in the Canada Basin are based on collections from early Arctic drifting stations (summarized by Mohr and Geiger 1968). The drift station data from the Alpha Cordillera area (1,000-2,500 m) and more recent studies in the deep Eurasian Basins and on the ridges (Kröncke 1994, 1998, Deubel 2000) and the deep Greenland Sea (Piepenburg et al. 2000) indicate comparatively low biomass from these Arctic deep-sea areas. According to the few available reports, dominant benthic taxa in the Canada Basin in terms of abundance were polychaetes, bivalves, crustaceans and sponges (Paul and Menzies 1974, Oceanol. 1978).

Our objectives in studying the Canada Basin benthos were (1) to identify habitats, species composition, abundance and biomass of major faunal components using ROV (Global Explorer, Deep-Sea Systems) in situ imaging in conjunction with box core samples; (2) to investigate the food web structure of the benthic community using stable isotope analysis; and (3) to investigate trophic links between the benthic, pelagic and ice-associated food webs of the deep Arctic Ocean, based on stable isotope analysis.

Due to various constraints, only eleven individual box cores were collected at six stations ranging from 625 m to 3,250 m along the cruise track (Aug.-Sept. 2002), from Amundsen Gulf to Northwind Ridge. Along with 853 still images, 9.2 hours of video were recorded. All quantitative materials are currently being analyzed. Preliminary data from photographic materials indicate that the most abundant epifauna taxa were polychaetes, fish (Liparidae, Zoarcidae), crustaceans (amphipods, isopods, decapods), ophiuroids and anemones. Whenever hard bottom was present (western basin), it was occupied by cnidarians, tube building polychaetes, ascidians and crinoids (both stalked and unstalked). So far, noteworthy differences between stations include the following: higher energy environment on the western slope of the basin (Northwind Ridge: more rocks, less lebensspuren, coarser sediment) with numerous suspension feeders; eastern deep basin: finer sediment, persisting lebensspuren, relatively more deposit/opportunistic feeders. Preliminary analysis of the box core samples indicated low macro-infauna abundances and biomass compared to lower latitudes. In terms of abundance, the dominant macro-infauna taxa were polychaetes, crustaceans (tanaids, cumaceans, ostracods, amphipods, isopods), and mollusks (bivalves, scaphopods). Among less frequent taxa were sponges, cnidarian tubes and ascidians. While not quantified, dominant meiofaunal groups were nematodes and harpacticoid copepods.

The $d^{15}N$ ratios are indicative of relative trophic relationships with a stepwise enrichment between trophic levels (TL) of 3-4‰. Mean $d^{15}N$ isotopic values for POM (particulate organic matter) from water samples across the Canada Basin at various depths was 5.1‰. Benthic animals ranged from 10.2‰ to 17.7‰ in their $d^{15}N$ isotopic values with most of the organisms falling into the second and third trophic level with respect to the POM values. This observation points toward little fresh phytodetritus reaching the seafloor resulting in organism associations that largely deposit feed on refractory material (e.g., many polychaetes) or are scavengers, predators or omnivores (e.g., amphipods). In contrast to the benthic system, distinctive herbivores (TL1) were present at the sea ice and the upper water column, as to be expected. Few pelagic/ice organisms fell within the third TL. The data suggest that the link between the pelagic/sea ice and the benthic system in late summer was through sinking of grazers and their products (e.g., fecal pellets, molts, dead animals) to the seafloor rather than through direct input of algal material to the benthos.

With regard to future recommendations for the Canada Basin project, better spatial coverage with adequate replicate sampling is recommended, both for biodiversity and food web diversity studies. Net tows should be added to collect macro-epifauna. The ROV capabilities need to be improved to obtain better camera settings and more ship independent operations. In terms of CoML, we recommend a high-resolution transarctic transect from the Eurasian to the American Arctic, covering all depth ranges but focusing on great depths. Methods should be uniform and should include traditional gear such as box cores and nets in combination with underwater imagery. Several selected small-scale assessments should be embedded in the large-scale survey. Several U.S. and Canadian coast guard/research icebreakers as well as coastal research facilities would potentially be available for the North American portion of a transarctic biodiversity study.

References

Clarke, A. 1983. Life in cold water: The physiological ecology of polar marine ectotherms. Oceanogr. Mar. Biol. Ann. Rev. 21:341-453.

Deubel, H. 2000. Structures and nutrition requirements of macrozoobenthic communities in the area of the Lomonosov Ridge in the Arctic Ocean. Ber. Polarforsch. 370:1-147.

Grebmeier, J.M., W.O. Smith Jr., and R.J. Conover. 1995. Biological processes on Arctic continental shelves: Ice-ocean-biotic interactions. In: W.O. Smith Jr. and J.M. Grebmeier (eds.), Arctic oceanography: Marginal ice zones and continental shelves. American Geophysical Union, Washington, D.C., pp. 231-261.

Hebbeln, D., and G. Wefer 1991. Effects of ice coverage and ice-rafted material in sedimentation in the Fram Strait. Nature 350:409-411.

Kröncke, I. 1994. Macrobenthos composition, abundance and biomass in the Arctic Ocean along a transect between Svalbard and the Makarov Basin. Polar Biol. 14:519-529.

Kröncke, I. 1998. Macrofauna communities in the Amundsen Basin, at the Morris Jesup Rise and at the Yermak Plateau (Eurasian Arctic Ocean). Polar Biol. 19:383-392.

Oceanol. 1978. Study of deep-water bottom fauna of the central part of the Arctic Ocean. Oceanol. 18:621.

Paul, A.Z., and R.J. Menzies. 1974. Benthic ecology of the High Arctic deep sea. Mar. Biol. 27:251-262.

Piepenburg, P., A. Brandt, K.v. Juterzenka, M. Mayer, K. Schnack, D. Seiler, U. Witte, and M. Spindler. 2000. Patterns and determinants of the distribution and structure of benthic faunal assemblages in the northern North Atlantic. In: P. Schäfer, W. Ritzrau, M. Schlüter, and J. Thiede (eds.), The northern North Atlantic: A changing environment. Springer, Berlin, pp. 179-198.

Canada and Arctic Marine Biodiversity Research

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History of data collection

Canada's Arctic marine coast embraces the Beaufort Sea to the west, dominated by the effects of the Mackenzie River and to the east, the vast island network of the Canadian Arctic Archipelago. Southward is Hudson's Bay, Hudson Strait, and Ungava Bay. South of 60º, Newfoundland and Labrador are bathed by the cold Labrador Current and receive icebergs from Greenland. Canadian records of its Arctic marine biodiversity date back 250 years to the early explorers and whalers in the North (Martin 2002, http://www.marinebiodiversity.ca/mbw/index.html). Expeditions searching for the Northwest Passage in 1818 through to 1833 carried naturalists on board and later expeditions in 1875 through to 1902 did as well. Currently, these data are being collated into the Science Data Inventory Database, for which the 247 Arctic records covering 1910 to 2000 are housed at Fisheries and Oceans Canada in Winnipeg, Manitoba (http://www.dfo-mpo.gc.ca/regions/central/index_e.htm). During the 20th century, much of the Arctic research was conducted at the Arctic Biological Station in Ste. Anne de Bellevue, Québec. Their products, which spanned 46 years of Arctic research, covered oceanography, phytoplankton, zooplankton, zoobenthos, fish, and marine mammals. Many of their research findings appeared in Fisheries Research Board Data Reports, and these can be obtained through interlibrary loan (http://inter01.dfo-mpo.gc.ca/wavesdocs/waves_mainmenu.html). Many of the Arctic specimens from this research are housed at the Canadian Museum of Nature (http://www.nature.ca). Arctic bird data are collected by the Canadian Wildlife Service (http://www.cws-scf.ec.gc.ca/index_e.cfm).

Additionally, Arctic marine biodiversity data for the western Arctic may be obtained at the Aurora Research Institute (http://www.nwtresearch.com/default.cfm) and in the eastern Arctic at the Nunavut Research Institute (http://pooka.nunanet.com/~research/). Universities also support northern research, and scientists who obtain logistical support through Canada's Polar Continental Shelf Project will have their projects listed on its Web site: http://polar.nrcan.gc.ca/home_e.html. Arctic marine information can also be found at the Arctic Institute of North America (http://www.ucalgary.ca/aina/) and the Canadian Polar Commission (http://polar.nrcan.gc.ca/home_e.htm). Other federal departments with responsibilities in the Canadian Arctic are Indian and Northern Affairs Canada (http://www.ainc-inac.gc.ca/), Natural Resources Canada (http://www.nrcan-rncan.gc.ca/inter/index.html) and Environment Canada (http://www.ec.gc.ca/).

Canadian Arctic marine biodiversity and biogeography

Surveying 18 publications and reports, Martin (2002) tallied 1,098 invertebrate species, 199 fish species, and 8 marine mammals that live in Canadian Arctic marine waters. Lee (1980) documented 382 species of macroalgae in the Canadian Arctic. Viruses, bacteria and protists would add a much higher number. The number of marine bacteria in the eastern Arctic is consistently in the range of 0.1-1.0 million cells/ml (Longhurst et al. 1989). Viruses are about 10 times this abundant (C. Suttle, University of British Columbia, pers. comm.). Diatoms and other large celled protists have been found at densities of 925,000 cells/l, with about 10-25% of primary production due to picoplankton and about 10% of enzyme activity deriving from ultramicroplankton cells <0.2 µm (Longhurst et al. 1989).

According to Wares (2002), the opening of the Bering Strait 3.5 million years ago resulted in a large interchange of marine life between Pacific and Atlantic coasts via the Arctic. The low salinity Pacific water is a conduit for propagules from the Bering Sea, transporting them eastward through the Beaufort Sea to the Canadian Arctic Archipelago, and thence to the North Atlantic through the Labrador Sea (Carmack and Macdonald 2002). Wares (2002) estimates that up to 80% of New England rocky shore fauna have a Pacific origin.

The western and eastern Arctic regions differ both in geography and in glacial history. The western Arctic, encompassing the Beaufort Sea and the Amundsen Gulf, has been controlled by the Mackenzie River for 60 million years. The Mackenzie is the fourth largest Arctic river and discharges an average of 333 km^3/yr (AMAP 1997). It is the only large river on the North American coast of the Arctic Ocean and its effects are felt deep into the Canada and Makarov basins (Guay and Falkner 1997). The freshwater plays a key role in the formation of sea ice (Aagard and Carmack 1989) which, in turn, determines the exchange of heat and moisture between the air and the sea (Maykut 1978). This constrains the strongly pulsed annual cycle of biological productivity (Legendre et al. 1992). The Mackenzie brings in not only large volumes of freshwater but also about 130 million metric tons of sediment/yr (Carson et al. 1998), a quantity greater than any other Arctic river (Carmack and Macdonald 2002). According to S. Blasco, Geological Survey of Canada (pers. comm.), the Mackenzie has deposited a 12,000 m thick layer of sediment on the coastal Beaufort seabed over this time. By comparison, the coast of the eastern Arctic is sediment starved as there are no large rivers feeding into it. During glaciation, ice was never on the western Arctic's Beaufort shelf as the climate was too dry. Only the Mackenzie Canyon was filled with an ice tongue. In the eastern Arctic, ice was grounded in the channel areas. The eastern Arctic is still rebounding about 30 cm/century whereas the Beaufort is actually sinking due to the weight of sediment deposited by the Mackenzie River. Even the climates of the eastern and western Canadian Arctic differ but they flip between heavy and light ice years in part due to changes in the Arctic Oscillation (Thompson and Wallace 1998). Climate warming will have marine effects such as longer ice-free periods, more wind-mixing, upwelling and wintertime brine rejection, thus increasing the availability of nutrients to phytoplankton, longer periods of light availability to phytoplankton and the benthos, increased export of organic terrestrial material to the coastal zone due to increased rainfall, rising sea level, more coastal erosion, and shifting water mass fronts and currents (Carmack and McLaughlin 2001).

The Canadian Arctic provides a diversity of habitat types for benthic marine life. The western Arctic is largely dominated by fine grained sediments but there are boulder beds off Herschel Island and sand beds farther east which may provide refugia for course-sediment inhabitants. Sea ice and icebergs scour long furrows to about 50 m water depth, creating a mosaic of recolonizing communities. Gas vents and submarine pingos provide unique habitats and drilling platforms alter the seabed, generating pits, islands, and hard substrates. Off the Mackenzie River are two canyons which funnel and exchange shelf water (Carmack and Macdonald 2002). The Mackenzie River itself pools into a 12,000 km^2 lake when it is dammed by the offshore stamukhi (pressure ridge) zone in the winter. This lake ranks 20th in the world by area and 30th by volume (Carmack and Macdonald 2002). A flaw polynya opens offshore of the stamukhi zone in late winter, leading eastward to the Cape Bathurst polynya. The fauna on the coast of the western Arctic are dominated in number and diversity by burrowing polychaetes. Large isopods, *Mesidotea* spp. are common near the Mackenzie inflow. Small bivalves, brittle stars, and a variety of tanaids, cumaceans and amphipods also inhabit the benthos. In the eastern Arctic, strong currents between the islands winnow the glacial sediment, leaving gravel and cobble for hard substrate attachment by macroalgae, sea anemones, and sea urchins. The coastal benthos is dominated in biomass by large clams, sea stars, sea cucumbers, sea anemones, soft corals, and sea urchins. Bedrock is exposed on the coasts of Ellesmere, Devon and Baffin Islands for soft corals, crinoids, and sponges to colonize. Such organisms also coat sunken ships, such as the *Bredalbane* off Beechey Island, which is in 100 m of water. These islands provide abundant fjord communities. Frobisher Bay on Baffin Island has extremely high tidal ranges, reaching up to 15 m. Under the polar pack ice above 130 m depth off Ellesmere Island, large siliceous sponges support a diverse benthic community and form reef mounds up to 10 m high (Van Wagoner et al. 1989). The North Water Polynya enhances productivity in northern Baffin Bay (http://www.fsg.ulaval.ca/giroq/now/). Numerous smaller polynyas occur in the eastern Arctic as well (http://www.fsg.ulaval.ca/giroq/now/polyb.jpg). Potential commercial fisheries are being evaluated for turbot, shrimp and clams and whales, walruses, seals and bears are hunted by the Inuit and Inuvialuit.

Pelagic organisms are influenced by stratification caused by the Mackenzie River inflow in the western Arctic. Different water masses from the Pacific and Atlantic may affect dispersal and isolation. Either phosphate or light (or both) limit primary production in the inner Canadian Shelf, while farther offshore, nitrate and light availability are the limiting factors (Carmack and Macdonald 2002). Under-ice organisms are limited by light penetration and nutrient supply and contribute only about 10-15% of the annual primary production in the western Arctic (Carmack and Macdonald 2002) and 5% in the eastern High Arctic (Longhurst et al. 1989). However, epontic algae extend the growth season for some Arctic zooplankton and, for the copepod *Pseudocalanus*, enables it to complete its life cycle in one year (Longhurst et al. 1989). Among the zooplankton, about 70% of the biomass in the top 250 m of the Canadian Arctic Ocean is composed of copepods, with about another 11% being pteropods and about 10% amphipods, with ostracods, coelenterates and appendicularians comprising most of the remaining biomass (Longhurst et al. 1989). Migratory birds depend on open water and a food supply available at the time of arrival. The eastern end of the Beaufort Shelf around Cape Bathurst is heavily used by eiders and long-tailed ducks for diving for benthic molluscan and crustacean prey (Dickson and Gilchrist 2002). Walrus prey on the large clams *Mya truncata* and

Serripes groenlandicus which are abundant in the eastern Arctic. The dynamics of polar bear populations are intertwined with those of their seal prey and sea ice thickness (Stirling et al. 1999, Stirling 2002). Separate populations of beluga whales congregate at the mouth of the Mackenzie River in the western Arctic and off Devon Island in the eastern Arctic. Bowhead whales are more abundant in the western Arctic than in the eastern but still suffer the population decimation of past European whaling. The Arctic cod, *Boreogadus saida*, is a key species transferring carbon from plankton to other fish (char and plaice), birds (murres, guillemots and kittiwakes), seals (harp and bearded), and whales (narwhal and beluga) (Longhurst et al. 1989). Anadromous fish such as cisco and char are seasonal components of Arctic marine biodiversity and their movements into the Arctic Ocean are tied to the hydrological cycle and its timing (Carmack and Macdonald 2002). In turn, the hydrological cycle is partly controlled by the ice, a feature affected by climate change. The diversity and stability of Arctic marine life is intimately linked to the dynamics of sea ice, and the potential effects of climate change on sea ice can be rapid and formidable. The consequences of climate warming for Arctic marine biodiversity will be huge.

Recent marine research programs in the Canadian Arctic

Beaufort Seabed Mapping Program (contact: Mr. Steve Blasco, blasco@agc.bio.ns.ca)

A joint geological and biological study of coastal features of the Beaufort Sea and associated biological diversity.

CASES: Canadian Arctic Shelf Exchange Study (http://www.giroq.ulaval.ca/cases/)

Based on the general hypothesis that the atmospheric, oceanic and hydrologic forcing of sea ice variability dictates the nature and magnitude of biogeochemical carbon fluxes on and at the edge of the Mackenzie Shelf, the major objectives of CASES are to assess:

1. The role of hydrologic, oceanographic and meteorological processes in ice growth, decay and transport on the shelf and beyond.
2. The hydrodynamic (including ice and snow cover dynamics) control of Arctic shelf photosynthetic production and its export to the benthos and the pelagic food web.

3. The potential impact of increased UV radiation on biological productivity.
4. The role of microheterotrophs and mesozooplankton in transforming particulate and dissolved matter on the shelf.
5. The fluxes of particulate matter and carbon across the shelf to the deep basins.
6. The distribution of riverine and airborne contaminants in the trophic web.
7. The potential impact of a reduction in ice habitat on birds and marine mammals.
8. The decadal and millennial variations in ice cover and their impact on ecosystem productivity.

NOW: International North Water Polynya Study (http://www.fsg.ulaval.ca/giroq/now/)

1. Physical mechanisms responsible for the opening, maintenance and closure of polynyas.
2. Effects of these mechanisms and the environmental characteristics of polynyas on ecosystems and carbon cycling.
3. Intercomparisons of the physics, chemistry, biology and carbon cycling in polynyas.
4. Interannual variability in the time of opening, extent, biological productivity and carbon sequestration in sediments of polynyas, based on remote sensing (sea ice, ocean color, etc.) and sediment records.

JWACS: Joint Western Arctic Climate Study (contact: Dr. Eddy Carmack, CarmackE@pac.dfo-mpo.gc.ca)

The study area focuses on the shelf-slope area of the Beaufort Sea and Central Arctic from the Northwind Ridge to Banks Island. The primary focus is on physical, biochemical and paleoceanography, but some biodiversity research is being conducted as well.

SBI: Western Arctic Shelf-Basin Interactions Project (http://nsidc.org/arcss/projects/sbi.html)

The Western Arctic Shelf-Basin Interactions (SBI) program is aimed at improving our understanding of shelf-basin exchange and should lead to improved predictions of global change impacts in the Arctic. The SBI program will include field and modeling studies directed at elucidating the physical and biological shelf and slope processes that influence the structure and functioning of the Arctic Ocean.

The SBI program is proceeding in three phases:

1. Phase 1 involves analysis of regional historical data, opportunistic field investigations, and modeling.

2. Phase 2 comprises core regional field investigations in the Chukchi and Beaufort seas, along with continued regional modeling efforts.

3. Phase 3 will investigate global change ramifications on the ecosystems of the Arctic shelves and basin. This phase will involve development of a pan-Arctic model (including embedded regional submodels) suitable for exploring hypothesized global change scenarios.

SHEBA: Surface Heat Budget of the Arctic Ocean (http://sheba.apl.washington.edu/)

SHEBA is a coordinated project to investigate the role of Arctic climate in global change. The primary goals of SHEBA are:

1. To determine the ocean-ice-atmosphere processes that control the surface albedo and cloud-radiation feedback mechanisms over Arctic pack ice, and to use this information to demonstrably improve models of Arctic ocean–atmosphere–ice interactive processes,

2. To develop and implement models that improve the simulation of the present day Arctic climate, including its variability, utilizing coupled global climate models.

Although primarily non-biological, some plankton research was conducted.

Facilities for research in the Canadian Arctic

Accommodation, equipment and transportation

Aurora Research Institute (http://www.aurresint.nt.ca/index.htm)
Nunavut Research Institute http://pooka.nunanet.com/~research/)
Polar Continental Shelf Project (http://polar.nrcan.gc.ca/home_e.html)

Ships

Canadian Coast Guard (http://www.ccg-gcc.gc.ca/)

Catalogues and guides to the identification of Canadian Arctic marine life

Phytoplankton

Tomas, C.R. (ed.). 1997. Identifying marine phytoplankton. Academic Press. 858 pp.

Macroalgae

Lee, R.K.S. 1980. A catalogue of the marine algae of the Canadian Arctic. National Museums of Canada, National Museum of Natural Sciences, Publications in Botany 9. 82 pp.

Polychaetes

Pocklington, P. 1989. Polychaetes of Eastern Canada. An illustrated key to polychaetes of Eastern Canada including the Eastern Arctic. Ocean Dumping Control Act Research Fund, National Museums of Canada, and Department of Fisheries and Oceans, Mont Joli. 233 pp.

Mollusks

La Rocque, A. 1953. Catalogue of the recent Mollusca of Canada. Canada Department of Resources and Development, National Parks Branch, and National Museum of Canada. Bulletin No. 129, Biological Series No. 44. Queen's Printer, Ottawa. 406 pp.

Lubinsky, I. 1980. Marine bivalve mollusks of the Canadian Central and Eastern Arctic: Faunal composition and zoogeography. Canadian Bulletin of Fisheries and Aquatic Sciences 207. 111 pp.

Macpherson, E. 1971. The marine mollusks of Arctic Canada. National Museums of Canada, National Museum of Natural Sciences, Publications in Biological Oceanography 3. 149 pp.

Amphipods

Barnard, J.L. 1959. Epipelagic and under-ice Amphipoda of the Central Arctic Basin. In: V. Bushnell (ed.), Scientific studies at Fletcher's Ice Island, T-3, 1952-1955. Terrestrial Sciences Laboratory, Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command, United States Air Force, Bedford, Massachusetts, AFCRC-TR-59-232(1) ASTIA Document No. AD-216813.

Just, J. 1980. Amphipoda (Crustacea) of the Thule area, Northwest Greenland: Faunistics and taxonomy. Greenland Bioscience 2. 61 pp.

Keast, M.A., and M.J. Lawrence. 1990. A collection of Amphipoda from the southern Beaufort Sea. Canadian Data Report of Fisheries and Aquatic Sciences 799. 114 pp.

Shoemaker, C.R. 1920. Report of the Canadian Arctic Expedition 1913-18. Vol. 7: Crustacea. Part E: Amphipods. Thomas Mulvey, Printer to the King's Most Excellent Majesty, Ottawa. 30 pp.

Shoemaker, C.R. 1955. Amphipoda collected at the Arctic Laboratory, Office of Naval Research, Point Barrow, Alaska, by G.E. MacGinitie. Smithsonian Miscellaneous Collections 128. 78 pp.

Isopods

Lawrence, M.A., and M.A. Keast. 1990. A guide to the identification of benthic Isopoda from the southern Beaufort Sea. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2048. 76 pp.

Percy, J.A., and F.J. Fife. 1980. Distribution, population structure and reproduction of Arctic marine isopods of *Mesidotea* complex in the southern Beaufort Sea. Canadian Data Report of Fisheries and Aquatic Sciences 198. 91 pp.

Mixed Crustacea

Dunbar, M.J. 1942. Marine macroplankton from the Canadian Eastern Arctic. I. Amphipoda and Schizopoda. Canadian Journal of Research 20:33-43.

Keast, M.A., and M.J. Lawrence (eds.) 1990. A guide to the identification of Decapoda, Euphausiacea and Mysidacea from the southern Beaufort Sea. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2047. 61 pp.

Sea stars

Grainger, E.H. 1966. Sea stars (Echinodermata: Asteroidea) of Arctic North America. Fisheries Research Board of Canada Bulletin 152. 70 pp.

Sea cucumbers

Deichmann, E. 1930. The holothurians of the western part of the Atlantic Ocean. Bulletin of the Museum of Comparative Zoology at Harvard College 71. 226 pp.

General invertebrates

Atkinson, E.G., and J.W. Wacasey. 1989. Benthic invertebrates collected from the western Canadian Arctic, 1951 to 1985. Canadian Data Report of Fisheries and Aquatic Sciences 745. 132 pp.

Hopky, G.E., M.J. Lawrence, and D.B. Chiperzak. 1994. NOGAP B2. Data on the meio- and macrobenthos, and related bottom sediment from Tuktoyaktuk Harbour and Mason Bay, N.W.T., March, 1985 to 1988. Canadian Data Report of Fisheries and Aquatic Sciences 939. 297 pp.

Hopky, G.E., M.J. Lawrence, S.M. McRae, and D.B. Chiperzak. 1994. NOGAP B.2. List of scientific names of algae, invertebrates, and vertebrates captured under NOGAP subprojects B.2.1 and B.2.3, 1984 to 1988. Canadian Data Report of Fisheries and Aquatic Sciences 924. 76 pp.

Wacasey, J.W., E.G. Atkinson, L. Derick, and A. Weinstein. 1977. Zoobenthos data from the southern Beaufort Sea, 1971-1975. Canadian Data Report of Fisheries and Aquatic Sciences 41. 187 pp.

Fishes

Scott, W.B., and M.G. Scott. 1988. Atlantic fishes of Canada. University of Toronto Press. 731 pp. (A comprehensive guide to the identification of Arctic marine fish is currently being developed by the Canadian Museum of Nature and Fisheries and Oceans Canada.)

Birds

Godfrey, W.E. 1986. The birds of Canada. Revised Edition. National Museum of Natural Sciences, National Museums of Canada. 595 pp.

National Geographic. 1999. Field guide to the birds of North America. National Geographic Society. 3rd edn. 480 pp.

Sibley, D.A. 2000. The Sibley guide to birds. National Audubon Society. Alfred A. Knopf, New York. 544 pp.

Mammals

Banfield, A.W.F. 1974. The mammals of Canada. University of Toronto Press. 438 pp.

Forsyth, A. 1999. Mammals of North America temperate and Arctic regions. Firefly Books. 350 pp.

Whitaker Jr., J.O. 1980. The Audubon Society field guide to North American mammals. Alfred A. Knopf, New York. 745 pp.

Wilson, D.E., and S. Ruff (eds.). 1999. The Smithsonian book of North American mammals. UBC Press. 750 pp.

References

Aagard, K., and E. Carmack. 1989. The role of sea ice and other fresh water in the Arctic circulation. Journal of Geophysical Research 94:14485-14498.

AMAP (Arctic Monitoring and Assessment Programme). 1997. Arctic Pollution Issues: A state of the Arctic environment report. Arctic Monitoring and Assessment Programme, Oslo, Norway. 188 pp.

Carmack, E.C., and R.W. Macdonald. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: A setting for marine life. Arctic 55(Suppl.1):29-45.

Carmack, E.C., and F. McLaughlin. 2001. Arctic Ocean change and consequences to biodiversity: A perspective on linkage and scale. Memoirs of the National Institute of Polar Research Special Issue 54:365-375.

Carson, M.M., J.N. Jasper, and F.M. Conly. 1998. Magnitude and sources of sediment input to the Mackenzie Delta, Northwest Territories, 1974-94. Arctic 51:116-124.

Dickson, D.L., and H.G. Gilchrist. 2002. Status of marine birds of the south-eastern Beaufort Sea. Arctic 55(Suppl.1):46-58.

Guay, C.K., and K.K. Falkner. 1997. Baryum as a tracer of Arctic halocline and river waters. Deep-Sea Research II 44:1543-1569.

Legendre, L. et al. 1992. Ecology of sea ice biota. 2. Global significance. Polar Biology 12:429-444.

Lee, R.K.S. 1980. A catalogue of the marine algae of the Canadian Arctic. National Museums of Canada, National Museum of Natural Sciences, Publications in Botany 9. 82 pp.

Longhurst, A.R., T. Platt, W.G. Harrison, E.J.H. Head, A.W. Herman, E. Horne, R.J. Conover, W.K.W. Li, D.V. Subba Rao, D. Sameoto, J.C. Smith, and R.E.H. Smith. 1989. Biological oceanography in the Canadian High Arctic. Rapports et Proces-Verbaux des Réunions Conseil International pour l'Exploration de la Mer 1888:80-89.

Martin, K. 2002. Marine biodiversity in the Canadian Arctic. In: The Centre for Marine Biodiversity: Draft proceedings from the Workshop on Canadian Marine Biodiversity. Census of Marine Life and the Department of Fisheries and Oceans, p. 25 (http://www.marinebiodiversity.ca/mbw/index.html).

Maykut, G.A. 1978. Energy exchange over young sea ice in the central Arctic. Journal of Geophysical Research 83:3646-3658.

Stirling, I., N.J. Lunn, and J. Iacozza. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic 52:294-306.

Stirling, I. 2002. Polar bears and seals in the eastern Beaufort Sea and Amundsen Gulf: A synthesis of population trends and ecological relationships over three decades. Arctic 55(Suppl. 1):59-76.

Thompson, D.W.J., and J.M. Wallace. 1998. The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. Geophysical Research Letters 25:1297-1300.

Van Wagoner, N.A., P.J. Mudie, F.E. Cole, and G. Daborn. 1989. Siliceous sponge communities, biological zonation, and recent sea-level change on the Arctic margin: Ice island results. Canadian Journal of Earth Science 26: 2341-2355.

Wares, J. 2002. Community assembly and possible generalities in the histories of Northwest Atlantic benthic invertebrates. In: The Centre for Marine Biodiversity: Draft proceedings from the Workshop on Canadian Marine Biodiversity. Census of Marine Life and the Department of Fisheries and Oceans, p. 23 (http://www.marinebiodiversity.ca/mbw/index.html).

Arctic Deep-Sea Biodiversity Research: The U.K. Perspective

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Arctic marine deep-sea biodiversity research: The known

Current knowledge of the deep-sea fauna of the deep European Arctic (Arctic, Norwegian, and Greenland seas) consists of both diversity studies and older faunistic studies (e.g., Sars 1885; Hansen 1916; Gurjanova 1930, 1933; Dahl et al. 1976; Svarvasson et al 1990, 1993; Brandt 1997) in addition to extensive faunistic works on the Greenland and Iceland continental shelves (e.g., Thorson 1933; 1936; Madsen 1936; Heegard 1941; Stephensen 1944; Piepenburg 1988; Brandt 1993; Brandt and Piepenburg 1994; Brandt et al. 1996, 1997). Many of the recent works (e.g., Brandt 1993, 1997; Brandt and Piepenburg 1994; Brandt et al. 1996) have focused on abundance and diversity patterns and, in many cases, highlighted the need for improved taxonomy in their species lists. For example, of 110 amphipod entities collected between 200 and 2,200 m on the Greenland continental shelf (Brandt 1997), 54 (~50%) were not identified to species level (i.e., were labeled either “cf.” or “*Genus* sp.” indicating problems in identification).

The most recent review of deep-sea biodiversity issues, Snelgrove and Smith (2002), summarizes the many processes that have been proposed to regulate biodiversity in deep-sea environments. The authors conclude that no single process is responsible for the high diversity of deep-sea ecosystems and that it is likely that a variety of non-equilibrium processes (such as disturbance, and spatial, and temporal patchiness in food supply), operating in a relatively stable, low productivity environment, will combine to enhance species diversity over a range of scales.

Snelgrove and Smith (2002) also discuss deep-sea species richness and the various estimates of global species number, (between

10^5 and 10^8 species) that have been calculated using reported examples of high local diversity in deep-sea environments. The debate as to whether or not the deep sea harbors greater species richness than shallow seas continues to this day with an entire literature being devoted to the subject. It is important to note that few large scale studies have been carried out in the deep-sea environment and therefore most researchers are comparing local diversities based on samples collected at single sites. The only genuine study of deep-sea biodiversity at a regional scale is that of Grassle and Maciolek (1992) who analyzed box cores collected along a 176 km transect of the Northwest Atlantic continental slope. The continuing debate clearly indicates the need for more such studies.

Especially relevant to Arctic biodiversity issues is the existence or otherwise of latitudinal diversity gradients in the deep sea. This has been another area of disagreement (Rex et al. 1993, 1997, 2000, 2001; Gray 1997, 2002; Culver and Buzas 2000; Lambshead et al. 2000, 2001a, 2002). Once again, claims that these gradients exist have been largely based on comparisons of local diversities based on samples collected at individual sites. It is also likely that historical factors exert a strong influence in some areas such as the Greenland-Norwegian Sea, which due to ice-cover during the last glaciation the fauna is likely to be evolutionarily younger and therefore possibly less diverse. The relationship between diversity and latitude is stronger in the North Atlantic but the relationship is significantly weakened when data from the Norwegian Sea is removed.

Arctic marine deep-sea biodiversity research: The unknown

The crucial "unknowns" that require work are as follows:

1. The apparent rarity of most species, and the fact that many are undescribed, hold progress back. Improvements to taxonomy are crucial to any census of marine life.

2. In order to have any confidence in deep-sea species richness assessments we need to scale up from local studies and studies on single taxa to larger and more comprehensive research programs.

3. Sampling programs need to study a wide variety of taxa, size classes, and functional groups at spatial scales of one kilometer, tens of kilometers (landscape scale), hundreds of kilometers (regional scale) and thousands of kilometers (basin and global scales). Without such knowledge, it is impossible to tackle the question of whether diversity in deep-sea environments is really

higher than diversity on the continental shelf (Gray 2002). The research effort required to address these aims is considerable and therefore best approached through international cooperation.

4. Issues relating to how the samples are collected are paramount. We must ensure that data sets are comparable (equipment and survey design) as is being recommended by NAGISA. In recent years, many studies in the Arctic have made use of epibenthic nets and/or box cores to carry out deep-sea diversity studies in the Arctic. However, during a recent environmental survey of the deep-water oil province off Angola, a comparative trial of macrobenthos samplers was carried out, which has shown that box corers lose about 50% of specimens and change the composition of the fauna (Bett et al., unpubl. data).

Overview of other Arctic biodiversity activities in the U.K., and collaborations with other national/international research groups

The **DEEPSEAS** benthic biology group at Southampton Oceanography Centre (SOC) is jointly funded by the Natural Environment Research Council through the George Deacon Division for Ocean Processes and the University of Southampton through the School of Ocean and Earth Science. The group consists of five prime movers, five post docs and fifteen Ph.D. students all working on aspects of deep-sea biodiversity and ecology. We have expertise in the taxonomy of deep-sea echinoderms, megafaunal and macrofaunal Crustacea, and meiofaunal Foraminifera and Nematoda. The group has been studying the deep-sea fauna for over 30 years and collectively has experience that totals more than 100 man-years in the ecology of the oceans. Our work covers a variety of habitats, from continental margins to abyssal plains and hydrothermal vents. In recent times, work has extended beyond taxonomy and ecology to molecular approaches.

The DEEPSEAS group has applied its research to the needs of government departments, industry (offshore oil and gas) and non-governmental bodies such as the World Wildlife Fund for Nature. DEEPSEAS has in recent years conducted six major field programs to map deep-sea habitats in areas of interest to deep-water hydrocarbon exploitation, resulting in the discovery of the coral-topped Darwin Mounds, areas that are now designated as the first U.K. offshore special area of conservation. DEEPSEAS is working closely with the Oil and Gas Producers Forum to establish good sampling protocols by the industry worldwide and making the samples taken in monitoring programs accessible to the scientific community. DEEPSEAS has a major program studying long-term change in the Northeast Atlantic (1989-2003), funded in part by European projects in Framework Programmes II, III, and IV, and has participated in three Framework V Programmes (ACES [Atlantic Coral Ecosystem Study], ECOMOUND [Environmental Controls on Coral Mounds], and OASIS [OceAnic Seamounts, an Integrated Study]). Other programs of interest at SOC include a study of soft-shelled foraminiferans from the fjords around Svalbard where they are very abundant. The project, led by Andy Gooday at SOC, is ongoing and aims to study the foraminiferans for genetic phylogenetic studies. A number of Ph.D. students and staff are involved in ANDEEP, a program to study the Antarctic benthos, and have experience of polar sampling.

Currently DEEPSEAS is involved with organization of the Census of Marine Life initiative, including hosting the office for the COML project on Chemosynthetic Environments (ChEss), and has recently been funded to organize a similar workshop to this to discuss the "Known, Unknown and Unknowable of the Biodiversity of Deep-Sea Sediments" on a global scale. This will be held in Oregon in August 2003 just prior to the Deep Sea Biology Symposium.

As the **BP Deep-Sea Biodiversity Research fellow** based at Southampton Oceanography Centre in the U.K., I am focusing my research on the Northeast Atlantic, in particular the regions to the west and north of the Shetland Isles where BP exploration is taking place. I am currently studying amphipod specimens collected during the AFEN (Atlantic Frontier Environmental Network) 1996 and 1998 and DTI 2000 and 2002 large-scale surveys to characterize the deep-water areas of the U.K. EEZ (Exclusive Economic Zone). My work is primarily taxonomic, aiming to improve problems of identification in the deep-sea amphipod fauna by describing new species and revising problem taxa. Many of the specimens I am studying are from the cold, deep waters north of the Wyville-Thomson Ridge and up into the Norwegian Basin.

As part of the BP Deep-Sea Biodiversity Research Fellowship, a collaboration has been initiated to make use of BP ROV downtime for scientific purposes. The first trials of this industry collaboration were last summer. During a two-week trip on board MSV *Regalia*, a number of successful deployments of holothurian traps were made to study feeding ecology, and observations of the megafauna led to improved understanding of the behavior of some common animals. The collaboration is set to continue with closer links and new projects.

SAMS–Northern Seas Programme

(See Burrows 2003, this volume)

British Antarctic Survey (BAS)

British Antarctic Survey carries out Arctic research, as a part of their program of polar research. The Natural Environment Research Council, the parent body of the British Antarctic Survey, supports environmental research in the Arctic at U.K. universities and research institutes. BAS is in the process of writing its science plans for 2005-2010, in the form of large grant proposals. BAS does have a small but strong biodiversity program, but at present work is concentrated in Antarctica. BAS would be interested in comparative data from the Arctic (for example specimens of the bivalve genus *Limopsis* to compare with Southern Ocean species), but at present has no formal Arctic program. The marine ecologists at BAS do have a bipolar interest, and it is possible that some themes may emerge as they shape their new round of science programs.

In 1991 the NERC International Arctic Environmental Research Station was established at Ny-Ålesund (79ºN 11ºE), on the High Arctic island of Spitsbergen, part of the Svalbard archipelago. The station, which supports mainly earth and life scientists is part of an international research community including stations owned by Norway, Germany, Japan, Italy, France, and the U.K. Ny-Ålesund is situated on the south side of the deep and sheltered Kongsfjord on the west coast of Spitsbergen. The southern shore alone provides 50 km of tundra and alluvial plain. Access to other shores and islands is possible by a NERC owned boat. Opportunities exist for researchers to carry out environmental research at Ny-Ålesund. This location is particularly suitable for ecological research, glacial/periglacial geomorphology, hydrology and atmospheric chemistry. The station provides laboratory space with limited equipment: glacier and boating equipment, radios, firearms (training provided), computers, telephone, fax, and email. There are seven bedrooms and those who cannot be accommodated by NERC use bedrooms owned by Kings Bay Company (the owners of Ny-Ålesund) who charge a daily board and lodging fee. Access is by light aircraft from Longyearbyen 100 km to the south. Longyearbyen receives scheduled flights daily from Norway.

Technological resources available to perform biodiversity work in your countries (icebreakers, ROVs, AUVs, etc.)

The Ocean Engineering Department at SOC comprises the Underwater Systems laboratory (USL) and U.K. Ocean Research Services (UKORS). USL tackles research and development projects in the broad area of platforms and sensors for ocean science. An organizational goal of USL is to benefit from interaction between ocean engineers at SOC and researchers. UKORS provide the scientific technical support in terms of equipment and staff to the U.K. marine science community principally in conjunction with the NERC Research Ships Programme. The National Marine Equipment Pool is managed by UKORS, which allows access to many pieces of sampling equipment (e.g., laboratory containers, winches, generators, corers, millipore system, moorings, dredges and trawls, computing, geophysics equipment, water sampling, and monitoring equipment).

Autosub

Autosub is an Autonomous Underwater Vehicle (AUV). AUVs are unmanned and untethered submersibles that are programmed to carry out missions without communication to the surface. One advantage of AUVs is that they can survey remote environments that are inaccessible to ROVs and other submersibles. Autosub can collect physical, chemical, biological and geophysical data from the ocean surface to the seabed using a suite of sensors and sampling devices tailored to individual mission requirements. Autosub technology has also been licensed to Haliburton Subsea for use in the oil, gas and subsea cable markets. Between 2001 and 2006, Autosub will return to the Polar Regions under the auspices of the **Autosub Under Ice Thematic Programme** in order to investigate (among other things) water circulation, how ice forms, and how the air, ice and ocean interact. The environment under ice shelves is one of the last great, unexplored regions of the planet. In July/August 2004, Autosub will be going under ice in North East Greenland. Nioghalvfjerdsfjorden Glacier (also known as NFG or 79ºN Glacier) drains 8.4% of the Greenland ice sheet area. The glacier enters Nioghalvfjerdsfjorden from the west and forms a floating ice tongue 60 kilometers long and 20 kilometers wide. One of the projects that will begin during this expedition is a study of "Controls on marine benthic biodiversity and standing stock in ice covered environments" led by Prof. Paul Tyler et al. For this project, a digital still camera system will be integrated with the Autosub vehicle and used to study the standing stock of benthos in Arctic and Antarctic regions. Seabed photography will be used to assess the megabenthos in three types of environment: (1) open water areas, (2) areas of seasonal ice cover and (3) areas of permanent ice cover. By contrasting the ecology of these three environment types, the project will address the question: "What are the dominant controls on the diversity and standing stock of the benthos in Polar Regions?"

ISIS

ISIS is the new U.K. Remote Operated Vehicle, based at the Southampton Oceanography Centre, U.K. *ISIS* has been developed in parallel with the ROV *Jason II* at the Woods Hole Oceanographic Institution, U.S.A., and can operate as deep as 6,500 m. She is equipped with a digital video camera, digital still photography camera, a number of sensors and two articulated arms for grabs and manipulations. The ROV is remotely operated from a control van on board the ship, where pilots and scientists can obtain data in real time. Sea trials of *ISIS* were completed in March 2003, during which *ISIS* was successfully deployed from RV *Atlantis* and tested on a series of dives to depths between 800 m and 4,300 m.

Ships

The NERC ship the RRS *James Clarke Ross* is normally found working in the Antarctic but has recently been taken to 81ºN with the Scottish Association of Marine Science, as part of the Northern Seas Programme.

The vessel is a Lloyds+100A1 Ice 1AS and is 99.04 m in length with a beam of 18.85 m. It has a double bottom ice strengthened hull. It has a maximum endurance of 57 days at sea. It can carry a maximum of 31 scientists and has a large amount of scientific deck space (650 m^2) consisting of a wet lab, main lab, rough workshop, scientific workshop, water bottle annex, chemistry lab, preparation lab, biochemistry lab, microbiology/radioactive lab, underway instrument and control room, electronics workshop, data preparation room, computer room and a darkroom.

The NERC ship the RRS *Ernest Shackleton* is an Antarctic logistics and marine science vessel. The vessel is a Det Norske Veritas *1A1 ICEBREAKER ICE 05 E0 HELDK ICS DYNPOS-AUTR W and is 80.00 m in length with a beam of 17.00 m. It has a double bottom ice strengthened hull. It can carry a maximum of 59 scientists and has a small wet lab and dry lab.

The NERC Research ship the RRS *Discovery* is currently being refitted and is a DTp VII, Lloyds 100A1 class vessel with a double bottom hull, capable of worldwide marine biology and oceanography research. It is 90.25 m in length with a beam of 14.00 m and has a maximum endurance of 55 days at sea. It can carry a maximum of 28 scientists and has a large amount of scientific deck space (460 m^2) consisting of an oceanographic wet lab, a multipurpose dry lab, chemistry lab, computer room, darkroom, plot and a constant environment lab.

References

Brandt, A. 1993. Composition, abundance, and diversity of peracarid crustaceans on a transect of the Kolbeinsey Ridge, North of Iceland. Polar Biology 13(8):565-576.

Brandt, A. 1997a. Abundance, diversity and community patterns of epibenthic- and benthic-boundary layer peracarid crustaceans at 75 degrees N off East Greenland. Polar Biology 17(2):159-174.

Brandt, A. 1997b. Suprabenthic Peracarida (Crustacea, Malacostraca) sampled at 75 degrees N off East Greenland. Polar Biology 17(5):462-464.

Brandt, A., and D. Piepenburg. 1994. Peracarid crustacean assemblages of the Kolbeinsey Ridge, North of Iceland. Polar Biology 14(2):97-105.

Brandt, A., and K. Schnack. 1999. Macrofaunal abundance at 79 degrees N off East Greenland: Opposing data from epibenthic-sledge and box-corer samples. Polar Biology 22(2):75-81.

Brandt, A., S.V. Vassilenko, D. Piepenburg, and M. Thurston. 1996. The species composition of the peracarid fauna (Crustacea, Malacostraca) of the Northeast Water Polynya (Greenland). Meddr. Grønland Biosci. 44:1-30.

Burrows, M.T. 2003. Arctic nearshore biodiversity research: The U.K. and Scottish view. In: Proceedings of the Arctic Biodiversity Workshop. Alaska Sea Grant College Program, University of Alaska Fairbanks. This volume.

Culver, S.J., and M.A. Buzas. 2000. Global latitudinal species diversity gradient in deep-sea benthic Foraminifera. Deep-Sea Research I 47:259-275.

Dahl, E., L. Laubier, M. Sibuet, and J. Stromberg. 1976. Some quantitative results on benthic communities of the deep Norwegian Sea. Astarte 9:61-79.

Grassle, J.F., and N.J. Maciolek. 1992. Deep-sea species richness: Regional and local diversity estimates from quantitative bottom samples. American Naturalist 139(2):313-341.

Gray, J.S. 1997. Gradients in marine biodiversity. In: R.F.G. Ormond, J.D. Gage, and M.V. Angel (eds.), Marine biodiversity: Patterns and processes. Cambridge University Press, Cambridge, U.K., pp. 19-34.

Gray, J.S. 2001. The measurement of marine species diversity, with an application to the benthic fauna of the Norwegian continental shelf. Journal of Experimental Marine Biology and Ecology 250:23-49.

Gray, J.S. 2002. Species richness of marine soft sediments. Marine Ecology Progress Series 244:285-297.

Gurjanova, E. 1930. Beitrage zur Fauna der Crustacea-Malacostraca des arktischen Gebietes. Zool. Anz. 86:231-248.

Gurjanova, E. 1933. Die Marinen Isopoden der Arktis. Fauna Arct. 6:390-470.

Hansen, H.J. 1916. Crustacea Malacostraca: The order Isopoda. Danish Ingolf Expedition 3:1-262.

Heegaard, P.E. 1941. The zoology of East Greenland: Decapod crustaceans. Meddr. Grønland Biosci. 121:1-72.

Lambshead, P.J.D., J. Tietjen, T. Ferrero, and P. Jensen. 2000. Latitudinal diversity gradients in the deep sea with special reference to North Atlantic nematodes. Marine Ecology Progress Series 194:159-167.

Lambshead, P.J.D., J. Tietjen, C.B. Moncrieff, and T. Ferrero. 2001a. North Atlantic latitudinal diversity patterns in deep-sea marine nematode data: A reply to Rex et al. Marine Ecology Progress Series 210:200-301.

Lambshead, P.J.D., C.J. Brown, T.J. Ferrero, N.J. Mitchell, C.R. Smith, L.E. Hawkins, and J. Tietjen. 2002. Latitudinal diversity patterns of deep-sea marine nematodes and organic fluxes: A test from the central equatorial Pacific. Marine Ecology Progress Series 236:129-135.

Madsen, H. 1936. Investigations on the shore fauna of East Greenland with a survey of the shores of other arctic regions. Meddr. Grønland Biosci. 100:1-79.

Piepenburg, D. 1988. Zur Zusammensetzung der Bodenfauna in der westlichen Framstrasse. Ber Polarforsch 52:1-118.

Rex, M.A., R.J. Etter, and C.T. Stuart. 1997. Large-scale patterns of species diversity in the deep-sea benthos. In: R.F.G. Ormond, J.D. Gage, and M.V Angel (eds.), Marine biodiversity: Patterns and processes. Cambridge University Press, Cambridge, U.K., pp. 94-121.

Rex, M.A., C.T. Stuart, and G. Coyne. 2000. Latitudinal gradients of species richness in the deep-sea benthos of the North Atlantic. Proceedings of the National Academy of Sciences U.S.A. 97:4082-4085.

Rex, M.A., C.T. Stuart, and R.J. Etter. 2001. Do deep-sea nematodes show a positive latitudinal gradient of species diversity? The potential role of depth. Marine Ecology Progress Series 210:297-298.

Rex, M.A., C.T. Stuart, R.R. Hessler, J.A. Allen, H.L. Sanders, and G.D.F. Wilson. 1993. Global scale latitudinal patterns of species diversity in the deep-sea benthos. Nature 365:636-639.

Sars, G.O. 1885. Zoology: Crustacea I: Norwegian North Atlantic Expedition, 1876-1878. 6(14):1-280.

Snelgrove, P.V.R., and C.R. Smith. 2002. A riot of species in an environmental calm: The paradox of the species-rich deep-sea floor. Oceanography and Marine Biology 40:311-342.

Stephensen, K. 1944. Crustacea Malacostraca V-VIII: Amphipoda I-IV. The Danish Ingolf Expedition Reports III-13:1-54.

Svarvasson, J., T. Brattegard, and J-O Stromberg. 1990. Distribution and diversity pattern of asselote isopods (Crustacea) in the deep Norwegian and Greenland seas. Progress in Oceanography 24:297-310.

Svarvasson, J., J.-O. Stromberg, and T. Brattegard. 1990. The deep-sea asselote (Isopoda: Crustacea) fauna of the Northern Seas: Species composition, distributional patterns and origin. Journal of Biogeography 20:537-555.

Thorson, G. 1933. Investigations on shallow water animal communities in the Franz Joseph Fjord (East Greenland) and adjacent waters. Meddr. Grønland Biosci. 100:1-70.

Thorson, G. 1936. The larval development, growth and metabolism of arctic marine bottom invertebrates compared with those of other seas. Meddr. Grønland Biosci. 100:1-115.